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USE OF IRRIGATION WATER ON FARM CROPS

By

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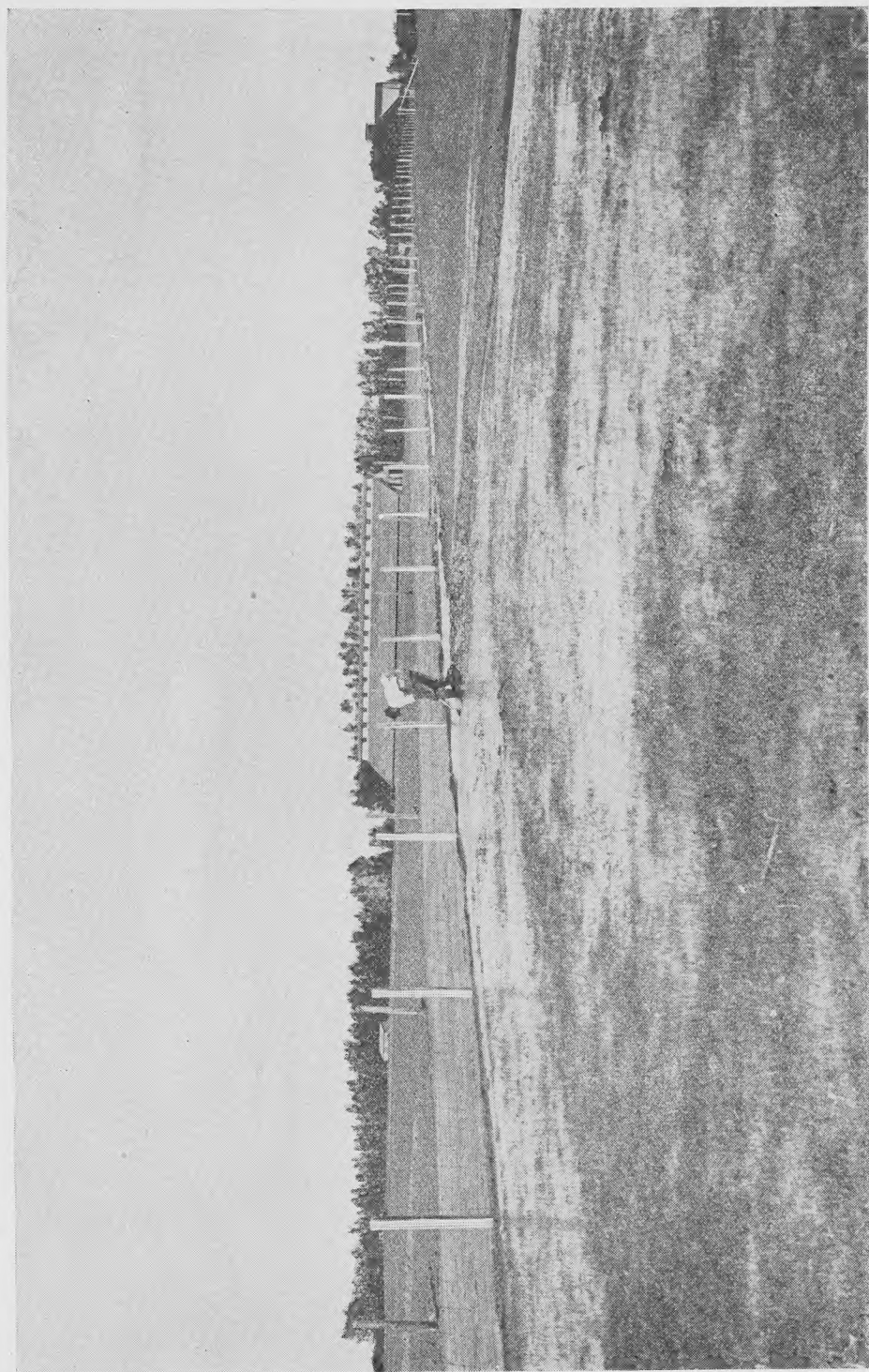


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USE OF IRRIGATION WATER ON FARM CROPS*†

INTRODUCTION

Each year irrigation is assuming greater importance in the agricultural development of Southern Alberta. In the ranching days of the eighties and nineties, water was diverted from a few small streams on to adjoining bottom lands to irrigate hay, but the bringing of water into Lethbridge through the canals of the Canadian North West Irrigation Company in 1900 was the beginning of extensive irrigation in Alberta. At the present time, the two Canadian Pacific Railway projects east of Calgary and the one at Lethbridge, the Canadian Land and Irrigation Company Project at Vauxhall, the Taber project at Taber, the United Project at Glenwoodville and Hillspring, the Lethbridge Northern, and a number of smaller projects, contain approximately one million acres of irrigable land.

The development of these lands has naturally given rise to numerous questions, among these being the proper use of irrigation water. The problem of the proper use of water has been complicated not only by the usual factors of variation in soil types and climatic conditions, but also by the fact that the irrigated projects have received settlers from different parts of the irrigated west, all of these having brought with them with their own ideas of irrigation as worked out in the localities from which they came. Many of the settlers have had no previous irrigation experience and look upon irrigation as something to be avoided except in cases of extreme drought. The whole situation is such that, even in places where irrigation has been practised for over twenty years, no general method has been worked out that seems to be entirely satisfactory.

Because of this situation it seemed necessary that detailed investigations be undertaken to study the problem. Numerous experiments on the use of water have been conducted in the irrigated parts of the United States. Much of their data has been of value in Alberta and is referred to freely in this report. Studies on the duty of water have also been made in Alberta by Snelson (37)* at the Department of the Interior Irrigation Experimental Station, Brooks, Alberta, supplemented by shorter experiments at Strathmore and Ronalane and by surveys of water use on farms in other parts of the province.

Purpose of Investigations

The experiments reported in this treatise were conducted at the Dominion Experimental Station, Lethbridge, Alberta, and were planned:—

1. To obtain information as to the stage of plant growth when water should be applied to field crops.
2. To study the value of fall irrigation.
3. To determine the number of irrigations required in different years by various crops.

* This paper (slightly modified) was used as a thesis submitted to the University of Alberta (Department of Field Husbandry) for the degree of Master of Science.

† The experiments were planned by the author under the direction of W. H. Fairfield, Superintendent of the Lethbridge Experimental Station. Mr. Fairfield also made helpful suggestions and criticisms during the progress of the work and has been of material assistance in interpreting the accumulated data. Dr. Robt. Newton and Dr. F. H. Wyatt of the University of Alberta made valuable suggestions and criticisms in the preparation of this report, and others, especially T. W. Grindley, helped with the conducting of the experiments, tabulating data and preparing the manuscript.

* Reference by number is to "Literature Cited" page 49.

4. To investigate certain phases of the inter-relations of soils, soil moisture, and plant growth.
5. To formulate standards of irrigation practice, from the data obtained, as well as from other information available, that will serve as a guide to the farmers on the developing irrigation projects of Alberta.

Experimental Methods

Crops used in the experiment were Marquis spring wheat, Grimm alfalfa, Irish Cobbler potatoes, sugar beets from commercial German seed, and Russian Giant sunflowers.

These crops were grown on plots containing one-twentieth or one forty-sixth of an acre and all tests were made in duplicate. Each plot was completely surrounded by a ditch seven feet wide. The bank of this ditch formed a dyke around the plot converting it into a basin. The ground inside the dike was levelled so that a uniform application of water could be made over the entire area.

Description of Soil

The soil where the plots were located is a medium sandy clay loam of chocolate colour. The physical analysis of soil samples taken where the various crops were grown is presented in table 1.

TABLE 1.—Mechanical Analysis of the top six feet of soils in plots used for Irrigation Experiments, Lethbridge*

Soils from	On air-dried basis				On water-free basis						
	Depth (ft.)	Moisture	Loss on ignition	Gravel greater than 2 mm.	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
		p.c.	p.c.	p.c.	p.c.	pc.	p.c.	p.c.	p.c.	p.c.	p.c.
No. 1—Alfalfa plots.....	1st.....	2.26	6.53	0.08	0.15	0.27	2.09	20.49	38.80	21.18	17.02
	2nd.....	1.96	10.74	nil	0.09	0.28	1.76	35.69	28.87	14.60	18.71
	3rd.....	1.74	9.65	"	nil	0.14	1.41	16.03	49.26	15.46	17.70
	4th.....	1.65	8.75	"	0.09	0.22	2.31	26.16	39.92	15.84	15.46
	5th.....	1.57	8.48	"	0.04	0.12	1.31	31.20	35.21	16.40	15.72
	6th.....	1.65	8.60	0.01	0.06	0.09	1.10	34.31	31.14	16.25	17.05
No. 2—Alfalfa plots.....	1st.....	1.94	11.13	nil	0.05	0.20	1.34	27.66	32.02	19.42	19.31
	2nd.....	1.48	11.03	"	0.02	0.11	0.78	28.38	37.28	14.74	18.69
	3rd.....	1.43	9.65	"	nil	0.08	1.20	35.36	29.41	13.34	20.61
	4th.....	1.36	8.48	"	0.08	0.15	1.33	36.88	32.20	13.52	15.84
	5th.....	1.45	8.29	"	nil	0.09	1.01	35.94	33.33	12.00	17.63
	6th.....	1.48	8.27	"	"	0.10	0.79	30.57	38.60	12.10	17.84
No. 3—Wheat and potato plots.	1st.....	2.29	5.60	0.02	0.06	0.22	1.28	23.77	29.72	26.60	18.35
	2nd.....	1.84	12.15	nil	nil	0.11	0.97	24.05	35.92	19.64	19.31
	3rd.....	1.54	10.03	"	"	0.01	0.41	22.40	41.54	18.83	16.81
	4th.....	1.42	9.36	"	"	0.03	0.45	23.59	40.98	18.83	16.12
	5th.....	1.52	8.91	"	"	0.07	0.95	26.17	36.72	18.70	17.39
	6th.....	1.61	8.35	"	"	0.11	1.65	34.00	29.26	15.64	19.34
No. 4—Wheat and potato plots.	1st.....	2.13	8.38	0.03	0.05	0.26	1.39	23.48	34.94	22.78	17.10
	2nd.....	1.77	11.81	nil	nil	0.13	0.69	20.46	37.51	21.38	19.73
	3rd.....	1.47	9.47	"	"	0.07	0.87	30.08	36.58	14.83	17.57
	4th.....	1.46	8.76	"	"	0.07	0.75	30.14	37.50	13.40	18.14
	5th.....	1.45	8.62	0.20	0.08	0.22	1.14	39.06	24.73	13.24	21.53
	6th.....	2.36	5.83	1.06	0.91	1.40	4.12	18.07	19.46	28.28	27.76
No. 5—Wheat and potato plots.	1st.....	2.60	5.78	nil	0.03	0.21	1.06	17.35	40.94	22.85	17.56
	2nd.....	1.74	12.42	0.05	0.02	0.06	0.75	18.68	40.58	19.02	20.89
	3rd.....	1.66	10.48	nil	nil	0.08	0.61	20.80	41.53	16.88	20.10
	4th.....	1.67	9.12	"	"	0.07	0.56	24.44	40.33	14.88	19.72
	5th.....	1.48	8.56	"	"	0.04	0.54	31.74	36.38	10.64	20.66
	6th.....	1.59	8.27	"	"	0.13	0.86	36.11	30.66	10.32	21.92
No. 6—Wheat and potato plots.	1st.....	2.11	5.00	nil	0.03	0.14	1.02	20.46	38.22	22.40	17.73
	2nd.....	2.20	4.03	"	0.01	0.13	0.83	17.63	40.39	22.81	18.20
	3rd.....	1.73	10.81	"	0.01	0.08	0.57	12.63	34.90	27.47	24.32
	4th.....	1.47	11.06	"	nil	0.03	0.44	17.31	39.34	18.16	24.72
	5th.....	1.36	9.55	"	"	0.05	0.53	22.53	39.81	15.90	21.18
	6th.....	1.45	9.02	"	"	0.03	0.61	20.75	41.14	16.75	20.72

NOTE.—Soil series No. 1 and No. 2 were from different parts of the field containing the alfalfa plots. No. 1 also represents the soil of sunflower plots.

Series Nos. 3, 4, 5 and 6 were from different parts of the wheat and potato plots. No. 3 was taken adjacent to the sugar beet plots.

* Analysis by Frank T. Shutt, Dominion Chemist, Central Experimental Farm, Ottawa, Ontario.

Cropping and Fertility Record of Soil

The wheat grown in 1922 was on land that had been in corn the previous year and in alfalfa for the ten years preceding. For four years before the alfalfa field was broken, it was used as hog pasture and the soil was in a high state of fertility. The wheat following wheat grown in 1923, except the plots that were fall-irrigated, was on this same land. The fall-irrigated plots were on land that supported a heavy crop of white sweet clover cut for hay in 1921 and a crop of wheat in 1922. The fertility of these plots was not quite equal to that of the balance of the field as shown by the uniformly lower yields of wheat on the fall-irrigated plots and on one check plot located in the same area. These plots were abandoned after two years as some underground seepage developed on one end of the field.

The wheat after cultivated crops of 1923 was grown on land that had supported a heavy growth of Russian Giant sunflowers the preceding year. This land was broken from alfalfa in 1921. The alfalfa was seeded in 1918 and had been cut for hay each year. Wheat after wheat in 1924 was seeded on the land just described and in 1925 these plots, which contained one-twentieth acre each, were divided by making a ditch seven feet wide down the centre of each plot. The resultant plots contained one forty-sixth acre each.

In 1924 another set of plots was established on an adjoining field which had the same cropping history and the three plot-sets were then rotated with two years of wheat and one year of potatoes.

Potatoes followed wheat each year on the land described above. All wheat and potato plots received a uniform application of twelve tons of well-rotted manure in the spring of 1927.

The alfalfa plots were seeded in 1922 on land that had been rotated with oats, potatoes and peas for six years.

Sunflowers were grown on land that had been in a rotation of oats, peas and potatoes. Potatoes were grown on this field in 1922. The sunflowers were grown on the same plots for the two years that they were included in the experiment.

Sugar beets were under test for three years beginning in 1925, and were grown on the same plots each year. The field where these plots were located was in beans in 1924, wheat in 1923, sunflowers in 1922 and alfalfa in 1921 and for three years previous. Thirty tons of well-rotted barnyard manure per acre were applied to the field and ploughed under in the fall of 1924.

All of the soil and subsoil where the various crops were grown appeared to be of uniform texture, structure and fertility over the entire fields, except as noted where the various crops are discussed in detail.

Cultural Practices

The cultural methods used on all crops were those which had proved to be best from previous work done at the Station.

Alfalfa was seeded in a well-prepared seed bed on June 23, 1922, on land that had been ploughed the preceding fall and kept free from weeds. Fifteen pounds of Grimm alfalfa seed per acre were sown in drills and without a nurse crop. The plots were given a three-inch irrigation immediately after seeding with the result that a perfect stand of alfalfa was obtained. The weeds and alfalfa on the plots were clipped twice during the first season.

The land prepared for wheat following wheat and for potatoes was ploughed in the spring to a depth of six inches and worked down immediately with a spike-tooth harrow, except for the crop of 1925. In the fall of 1924, these plots were fall-ploughed. In preparing land for wheat following potatoes, the plots were cultivated with a duck-foot cultivator in the fall after the potatoes were harvested, to assist in checking winter drifting, and were cultivated again in the

spring and harrowed before seeding. A pure strain of Marquis wheat was seeded with a 19-run, double disk drill, at the rate of ninety pounds of seed per acre.

Irish Cobbler potatoes were planted in rows three feet apart and to a depth of four inches with a two-man, horse-drawn planter. Certified seed potatoes were used at the rate of 1,300 pounds per acre, the sets having been cut to two eyes to the set. Before cutting the sets, the potatoes were soaked for four hours in a one-to-two thousand solution of mercury bichloride. The potato crop was cultivated from three to four times each year and furrows were made between rows for irrigating.

The sugar beet land was ploughed in the fall except for the crop of 1926. In that year, the beet plots were not ploughed but were cultivated in the fall and harrowed in the spring before seeding. The beets were seeded in rows twenty-two inches apart with a special beet drill of the shoe type. Seventeen pounds of seed were used per acre. The beets were thinned when in the four- to six-leaf stage to twelve inches apart in the rows and cultivated and hoed as needed. Furrows were made between the rows before each irrigation.

Before harvesting, a border at least three feet wide was trimmed from the perimeter of each plot of all crops under test.

Irrigation

The water used was obtained from the canal of the Canadian Pacific Railway's Lethbridge project and was led to the fields in earth ditches. Before reaching the plots the stream was passed through a side-overflow weir constructed to give a constant head of water. The water was measured over a rectangular weir of one-foot crest at the head of the alfalfa and sunflower plots and over a moveable, triangular-notch weir at the head of the other plots. The amount of water passing over the weir was determined by tables given by Murdock and Barker (30). From these tables other tables were constructed showing the number of minutes required for a given application with varying heads of water.

All alfalfa and grain plots reported here received an application of six acre-inches of water per acre at each application except in 1927 when due to the unusually heavy rainfall the irrigations were reduced to three inches. Potatoes, sugar beets and sunflowers received four inches where but one irrigation was given and three inches where more than one irrigation was made.

In every instance, the date of application of water was gauged by a definite stage of plant growth or at a uniform period after such a stage where the habits of growth of the plant made it impractical to specify stages of growth. For example, wheat was irrigated in the one-leaf, three-leaf, five-leaf, shot-blade, flowering and soft-dough stages. These are all stages of growth easily distinguished. Potatoes were irrigated when the plants were half-grown, starting to bloom, and in full-bloom. Irrigations applied to potatoes after the full-bloom stage were placed at fixed intervals of ten or twenty days as there were no readily distinguishable growth stages after the potatoes were in full-bloom.

The reason for selecting stages of growth instead of fixed dates was that plants appear to have different water requirements at different stages of growth. Investigations conducted by Bark and Palmer* showed that wheat and barley grown in tanks increased their daily use of water as growth increased until the plants reached full height. The use then remained almost constant until ripening commenced when the amount of water used decreased abruptly and became almost nil when the plants were ripe. While working in Idaho, Bark (2) found that grains required the largest amount of water at the flowering or soft-dough stages, but that alfalfa, clover and pasture should be kept uniformly moist throughout the season. According to the experiments of Snelson (37), the water

* Unpublished data.

requirements of wheat were greatest in June, while the rate of plant growth was most rapid in July. Widtsoe and Merrill (48) state that "The time at which water is applied to crops determines, largely, the yield" and that "July is the month when most of the water should be applied to a beet field, with August applications following very closely in value, while in September a very small amount, indeed, suffices to maintain growth." In a later publication, Widtsoe and Stewart (49) state that "During the early periods of growth, plants need less water than during later periods."

Buffum (7), writing in 1892, made this interesting statement: "Wheat needs the most water during its early period of growth. Just before heading if the ground does not contain enough moisture to last until the crop will mature, it should be irrigated, as water applied after the heads are formed is liable to induce rust."

Fortier (13) says: "The amount of water required by cereals during the first six weeks of their growth is small if one excepts the heavy loss by evaporation from the surface of newly cultivated and seeded fields. The amount of water required during the last three weeks is likewise small."

From the results of tank and field experiments, Thom and Holtz (39) concluded that the daily amount of water transpired by wheat, corn, oats and peas increased until about the beginning of the ripening period. From this time there was a gradual decrease up to maturity.

Soil Moisture Determinations

Moisture determinations were made of each foot of soil to a depth of six feet in the spring at seeding time, immediately before and after each irrigation, and in the fall after harvest. From one to four borings were made on each plot at each sampling.

Soil samples were secured with a soil tube of the Briggs type, and the moisture was determined by oven drying to constant weight at 100° C. to 110° C.

Meteorological Observations at Lethbridge

Irrigation water is applied primarily to supply moisture to the soil for plant use. It is, therefore, evident that variations of rainfall and other climatic conditions influencing soil moisture content, evaporation and transpiration, greatly affect the constancy of results obtained from irrigation experiments conducted under field conditions.

The monthly and annual precipitation at Lethbridge for the six years that these experiments have been under way, together with the average precipitation for the twenty-six years that observations have been made, are presented in table 2. The precipitation for the months when the rainfall has the principal effect on the crop of that year, April to August, inclusive, is also given. In table 3 are introduced data on the evaporation from a free water surface for the months of May to October, inclusive. The mean wind velocity for each of the months of April to October, inclusive, and the total hours of bright sunshine for the same months are listed in tables 4 and 5 respectively.

Of all the weather factors, precipitation has, perhaps, the greatest influence on irrigation and varies the most from year to year. A study of table 2 shows a difference in the total precipitation of 1922, which had the lowest precipitation, and 1927, which had the highest, of 48.4 per cent, and a difference in the precipitation of the cropping season, of 42.9 per cent. The difference between the evaporation of 1924, which was the highest, and 1927, which was the lowest, was 23.8 per cent, while the differences in the years having the highest and lowest mean wind velocity and sunshine were still less.

The six-year period had three comparatively dry years, 1922, 1924 and 1925, as indicated by the rainfall of the cropping season. The precipitation received in 1926 was supplemented to a marked extent by the unprecedented September and October precipitation of 1925, which was the equivalent of a good fall irrigation. The fall of 1926 was also wet, which condition, coupled with the heavy rainfall of May, 1927, and timely rains of June and July, provided ample moisture without irrigation for potato, sugar beet and grain crops, and for the first cutting of alfalfa.

TABLE 2.—Inches of Precipitation at Lethbridge, 1922-1927

Months	1922	1923	1924	1925	1926	1927	Average 26 years
	in.	in.	in.	in.	in.	in.	in.
January.....	0.43	0.48	0.66	0.30	0.24	0.31	0.63
February.....	0.41	0.42	1.04	0.99	0.76	1.39	0.68
March.....	0.81	0.75	0.69	2.26	0.11	0.37	0.69
April.....	2.57	1.09	0.56	1.99	0.34	1.48	0.95
May.....	0.89	3.48	1.17	0.43	0.64	7.32	2.58
June.....	1.87	4.45	3.82	3.40	4.67	1.60	2.77
July.....	2.30	2.55	0.54	0.82	1.15	1.93	1.82
August.....	0.40	1.01	2.91	1.85	2.31	1.74	1.77
September.....	0.81	0.18	1.46	4.86	4.62	3.29	1.82
October.....	0.78	0.55	0.59	1.08	0.31	0.58	0.82
November.....	0.47	0.53	1.02	0.16	0.52	2.88	0.67
December.....	0.60	0.91	1.54	0.62	0.56	0.96	0.63
Total for crop season.....	8.03	12.58	9.00	8.49	9.11	14.07	9.89
Total for year.....	12.34	16.40	16.00	18.76	16.23	23.85	15.83

TABLE 3.—Inches of Water Evaporated from a Free Water Surface at Lethbridge, May to October, 1922-1927

Months	1922	1923	1924	1925	1926	1927
	in.	in.	in.	in.	in.	in.
May.....	4.66	5.08	5.97	3.71	6.24	3.36
June.....	4.94	5.49	4.43	4.82	5.37	3.83
July.....	4.51	4.52	6.13	7.02	5.60	4.00
August.....	4.77	4.28	4.14	6.05	4.58	3.78
September.....	4.05	3.42	3.93	3.44	1.77	3.16
October.....	3.17	1.74	2.29	1.09	3.05	2.38
Total.....	26.10	24.53	26.89	26.13	26.61	20.51
Monthly average.....	4.35	4.09	4.48	4.35	4.43	3.42

TABLE 4.—Monthly Mean Velocity of Wind in Miles per Hour at Lethbridge, April to October, 1922-1927

Months	1922	1923	1924	1925	1926	1927
April.....	12.7	11.1	13.6	11.9	11.4	14.4
May.....	13.9	11.8	8.6	11.2	13.5	13.4
June.....	9.6	9.6	7.9	9.7	11.1	9.9
July.....	7.8	5.0	7.3	7.8	8.2	7.0
August.....	10.4	4.5	8.2	9.7	7.8	7.9
September.....	13.4	6.7	10.5	7.9	7.5	10.7
October.....	10.6	10.1	12.4	8.4	12.3	13.4
Seven-month average.....	11.2	8.4	9.8	9.5	10.3	11.0

TABLE 5.—Monthly Hours of Bright Sunshine at Lethbridge, April to October, 1922-1927

Months	1922	1923	1924	1925	1926	1927
April.....	152.6	235.6	207.9	199.1	239.8	221.4
May.....	254.9	270.6	281.4	335.1	244.6	135.6
June.....	267.2	235.9	226.4	279.7	292.9	287.1
July.....	302.1	287.6	324.4	305.0	343.7	308.5
August.....	268.9	274.8	243.0	318.0	246.3	273.3
September.....	198.1	212.8	227.0	151.0	160.1	182.0
October.....	157.3	184.4	151.9	106.2	196.9	178.7
Total.....	1,601.1	1,701.1	1,662.0	1,694.1	1,724.3	1,586.6

IRRIGATION OF WHEAT

Much literature is available reporting experiments with the irrigation of wheat. Only that is cited in this paper which seems to bear especially on the problem here involved; that is, the optimum time and frequency of irrigation.

Review of Literature on Irrigation of Wheat

In tests at Brooks and Ronalane, Alberta, Snelson (37) received maximum yields of wheat with five four-inch irrigations. Under the different conditions found in Utah, Widtsoe and Merrill (48) obtained greater yields of grain from one light irrigation of 3.5 inches applied when the heads were filling out than when this irrigation was applied soon after the middle of June when the plants were smaller. Widtsoe (44) states that "it is seldom necessary to give wheat more than three irrigations except, possibly, in the hot climate of Arizona and similar regions. In fact, two irrigations are usual, and one irrigation ordinarily ample wherever the annual precipitation is between 12 and 15 inches." Smith (36) recommends irrigating wheat when just out of the boot. From experiments conducted in Utah in 1890 to 1893, Sanborn (35) obtained increased yields of wheat in three years out of four when an irrigation in early May was given in addition to three later irrigations as compared to the three later irrigations only.

At the Gooding Substation, Idaho, Welch (42) obtained the best yields with three irrigations applied in the jointing, booting and heading stages. Two irrigations applied in the jointing and heading stages gave but slightly lower yields, while two applied in the booting and heading stages gave 2.3 bushels less than the three irrigations. Where but one irrigation was given, the best yield was secured when this was applied in the jointing stage. One irrigation applied in the booting stage gave better results than a later irrigation. Irrigating at the time of heading appeared to be of no value. Fortier (12) says that "when grain is heading out is the critical period of its irrigation." A field at Lethbridge, Alberta, is reported by Porter (33) that yielded 31 bushels per acre with an irrigation the first week in June. Part of the same field irrigated ten days later yielded 26 bushels per acre and another irrigated on June 17 produced 19 bushels per acre. A part of this field not irrigated gave a yield of 15 bushels per acre.

In a carefully conducted experiment at the Colorado Station, where canvas roofing was used to keep all precipitation off the plots, Kezer and Robertson (22) obtained the highest yield where only one six-inch irrigation was given, when this was applied in the jointing stage. The plots irrigated at heading yielded a little less. Plots irrigated at germination or tillering yielded less than those irrigated at jointing or heading. The difference in yields when water was applied at germination and at tillering was so small that there was no real significance between the two. When water was applied at the filling stage, it was of little benefit to the crop.

The greatest yield of wheat was secured by Knight and Hardman (26) in Nevada, when irrigations were applied in the boot, bloom, milk and soft-dough stages. Another irrigation applied in the five-leaf stage did not increase the yield. When only three irrigations were given, the best times of application were at the boot, bloom and milk stages of growth.

In a four-years' test (1912-15) at the Utah Station on a loam soil quite similar to the Lethbridge Station soil and with an annual rainfall also similar, Harris (15) obtained the greatest yield of wheat with three irrigations applied at the five-leaf, the early-boot and the bloom stages. Where only one irrigation was given, the best time to give it was in the five-leaf stage. Where two irrigations were applied, the five-leaf and boot stages were best. Water applied after the grain was planted, but before it was up, and that applied after the dough stage decreased the yield. He also found that water applied during early growth increased the height of wheat more than water applied at any other time and that the maturity of wheat was retarded by excessive irrigation.

The same author (16), when working with a clay loam soil in pots, found that wheat matured sixteen days earlier with 20 per cent moisture in the soil than with either 11 per cent or 45 per cent moisture, and that the period at which high moisture was applied had considerable effect on the date of ripening. The number of kernels to each head was greatest on soil with medium moisture content but the weight of 100 kernels was greatest on the driest and lowest on the wettest soil.

Working in Nevada, in 1911, True (38) obtained the best yields of wheat from three irrigations before heading and two irrigations after heading. In 1913, two irrigations before and two after heading gave the highest yields.

Four to six irrigations were found necessary by Bloodgood and Curry (6) for highest yields of wheat at the New Mexico Station.

In the Quetta Valley, India, Howard and Howard (18) with a single irrigation and appropriate mulch-producing cultivation obtained 1,450 pounds of wheat per acre. The native average was 1,100 pounds with the customary methods, involving seven irrigations.

Chiritescu-Arva (8) applied different amounts of water to wheat in containers of rolled zinc at three stages of growth—the green-shoot period, the ear-shooting period and the ripening of the ear period. The water optimum had the most beneficial effect on the green-shoot period on the following growth factors: number of ears per plant, total length of ears of single plant, number of fertile spikelets, number of grains per single plant and ear, weight of ears in single plant, average weight of an ear, and grain weight per single plant and ear. The water optimum had a more beneficial effect in the ear-shooting stage than in either of the other stages on the following factors: development of spikelets, density of spikelets, density of grains, number of grains in single spikelets, weight per 1,000 grains, development of ears and grains in proportion to total yield and development of parts above ground and of grains in proportion to weight of ears.

Moliboga (29) obtained better results with wheat by moistening the soil in the shooting stage than by moistening in the tillering, earing or milky-ripeness stages.

Application of Water to Wheat at Lethbridge

In these experiments wheat received from one to four irrigations at different stages of plant growth as shown in the following schedule:—

A. One irrigation—

1. Previous fall.
2. Three-leaf stage.
3. Five-leaf stage.
4. Shot-blade stage.
5. Flowering stage.

B. Two irrigations—

1. Previous fall and shot-blade stage.
2. Previous fall and flowering stages.
3. Five-leaf and flowering stages.
4. Shot-blade and flowering stages.

C. Three irrigations—

1. Previous fall, shot-blade and flowering stages.
2. Five-leaf, shot-blade and flowering stages.

D. Four irrigations—

1. Previous fall, five-leaf, shot-blade and flowering stages.
2. Five-leaf, shot-blade, flowering and soft-dough stages.

E. When the crop appeared to need an irrigation.

One series of plots was left unirrigated as a check.

Yields of Grain Harvested

In table 6 is given the yield of threshed grain obtained for the years 1922 to 1927 inclusive, with the various irrigation treatments applied to wheat on plots that had grown a cultivated crop the preceding year. Corn preceded the crop of 1922, sunflowers the crop of 1923, and potatoes preceded the wheat crops of the last four years.



Part of wheat plots at harvest, showing ditches ploughed in and borders trimmed. Note that some plots have been harvested before others. In dry years the time of ripening may be materially influenced by the irrigation treatment.

When this experiment was started in the spring of 1922, no land was available that had been irrigated the previous fall, so that no tests were made of fall-irrigated land until 1923. The series receiving water in the three-leaf stage was also started in 1923, thus giving but five years' data for the fall and three-leaf periods. As part of the test was conducted for six years, a six-year average is shown of all the tests conducted for that length of time and a five-year average is given for all the tests made.

In table 7 are listed the annual yields and five-year averages of the threshed grain obtained from wheat planted on land that had produced a crop of wheat

the preceding year. An additional irrigation treatment, an application of water in the three-leaf and flowering stages, was added to this experiment in 1925. This addition was made because a lower yield was obtained in the dry year of 1924 from one irrigation applied in the three-leaf stage than from an irrigation applied in either the five-leaf or shot-blade stages. One reason for this lower yield appeared to be that the grain on the earlier irrigated plots suffered more for water before the plants matured than did the grain on the plots irrigated later. An important reason for applying an irrigation in the three-leaf stage was to test the correctness of the usually accepted opinion that irrigating grain before it was high enough to shade the ground materially reduces the yield. It seemed advisable, therefore, to include another irrigation in addition to the early one so that if a low yield were obtained, it could be determined whether this was due to the injurious effect of irrigation on the young plants or to a need of water in the later stages of growth.

TABLE 6.—Yields in Pounds per Acre of Wheat following a Cultivated Crop, Irrigated at Different Stages of Growth

Number of irrigations	Stages of plant growth when water was applied	Yields of grain in pounds per Acre							
		Six-year average	Five-year average	1922	1923	1924	1925	1926	1927
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
0	Dry.....	2,350	2,281	2,694	1,716	2,352	3,186	1,452	2,700
1	F.....	2,446	2,446	2,376	2,376	2,754	3,648	1,230	2,220
1	3 L.....	2,570	2,570	1,860	2,556	3,480	2,052	2,904	2,904
1	5 L.....	2,659	2,530	3,300	1,932	2,364	3,198	1,992	3,168
1	S.B.....	2,813	2,670	3,528	2,178	2,406	3,360	1,938	3,468
1	Fl.....	2,456	2,381	2,832	1,986	2,484	2,646	1,848	2,940
.....	Crop Needs.....	2,790	2,518	4,152	2,082	2,664	2,808	2,214	2,820
2	F, S.B.....	2,545	2,545	2,190	2,700	3,132	1,716	2,988	2,988
2	F, Fl.....	2,647	2,647	2,310	2,904	3,348	1,866	2,808	2,808
2	5L, Fl.....	2,710	2,497	3,774	1,998	2,622	3,372	2,148	2,346
2	S.B, Fl.....	2,765	2,600	3,588	1,986	2,376	3,372	2,376	2,892
3	F, S.B, Fl.....	2,615	2,615	2,352	2,904	2,736	2,178	2,904	2,904
3	5L, S.B, Fl.....	2,800	2,686	3,372	2,292	2,214	3,294	2,652	2,976
4	5L, S.B, Fl, S.D.....	2,772	2,707	3,096	2,280	2,340	3,324	3,012	2,580
4	F, 5L, S.B, Fl.....	2,532	2,532	2,286	2,646	2,508	2,244	2,976	2,976

Abbreviations used: F.—Fall, 3L.—3 leaf, 5L.—5 leaf, S.B.—shot blade, Fl.—flowering, S.D.—soft dough.

TABLE 7.—Yields in Pounds per Acre of Wheat Following Wheat, Irrigated at Different Stages of Growth

Number of irrigations	Stages of plant growth when water was applied (1)	Yields of grain in pounds per Acre					
		Five-year average	1923	1924	1925	1926	1927
		lb.	lb.	lb.	lb.	lb.	lb.
0	Dry.....	1,793	2,388	240	2,292	1,680	2,364
1	Fall.....	2,272	2,214	1,650	2,892	2,058	2,544
1	3L.....	2,233	3,270	1,608	2,136	2,124	2,028
1	5L.....	2,390	2,838	1,692	2,616	2,022	2,784
1	S.B.....	2,360	3,216	1,878	2,700	1,368	2,640
1	Fl.....	2,054	2,472	1,272	2,538	1,560	2,430
.....	Crop Needs.....	2,240	2,700	1,986	2,400	1,560	2,556
2	F, S.B.....	2,090	2,310	1,638	2,292	1,680	2,532
2	F, Fl.....	2,071	2,406	2,118	2,160	1,668	2,004
2	3L, Fl.....	(2)2,420	.....	.....	2,970	2,112	2,178
2	5L, Fl.....	2,328	2,988	2,004	2,508	2,136	2,004
2	S.B, Fl.....	1,976	2,472	1,626	2,106	1,362	2,316
3	F, S.B, Fl.....	2,279	2,142	2,202	2,508	1,956	2,586
3	5L, S.B, Fl.....	2,508	3,174	2,028	2,886	1,968	2,484
4	5L, S.B, Fl, S.D.....	2,278	2,910	1,998	2,724	2,112	1,644

(1) Abbreviations used: F.—Fall, 3L.—Three leaf, 5L.—Five leaf, S.B.—Shot blade, Fl.—Flowering, S.D.—Soft dough.

(2) 3-year average.

A comparison of tables 6 and 7 shows that the yields of wheat were decidedly better following a cultivated crop than following a crop of wheat in every year except 1923. The lower yields of that year following the cultivated crop were undoubtedly due to the fact that sunflowers were the cultivated crop grown the preceding year. Subsequent work has shown that sunflowers leave the soil in poor condition for a grain crop.

Value of Fall Irrigation

Seven direct comparisons are possible between fall irrigation and irrigations at other periods of the year. Fall irrigation on the wheat following wheat gave slightly lower average yields than was secured from comparable plots. This lower average was not great, however, and was caused principally by the poorer crop obtained on all of the fall-irrigated plots in 1923. As previously stated the land where the fall-irrigated plots were situated in 1923 proved to be inferior in fertility to the other plots of that year. There was no consistent difference in yields in the other four years.

The wheat following a cultivated crop irrigated in the fall gave a slightly lower average yield when but one irrigation was applied than where an irrigation was given in the three-leaf, five-leaf or shot-blade stages, while the fall-irrigated plots gave a higher average than the other plots when additional water was applied during the growing season. The average differences were not large, however, and were not consistent from year to year. The crop yield data agree with the opinion formed in watching the crops from year to year—that a fall irrigation for grain on a medium-textured soil is about equal to an irrigation applied during the growing season if the latter irrigation is given before the crop becomes too dry.

Early Irrigation for Wheat

The opinion is prevalent among irrigation farmers that it is detrimental to grain crops to irrigate them before the plants are high enough to shade the ground. This experiment did not support such an opinion as the plots irrigated when but three leaves had appeared, gave practically the same yield as was obtained when the irrigation was postponed until the five-leaf stage, which was approximately two weeks later, or until the shot-blade stage, twenty-five days later. When the water was applied in the three-leaf stage, the plants turned yellow and for a few days appeared to be injured by the water, but within a week they had regained their colour and for the balance of the year were as thrifty as adjoining plots irrigated at a later date. It is undoubtedly this temporary yellowing of the plants that has caused irrigators to think that early irrigation is detrimental to grain.

It should be remembered that these results were obtained on a sandy clay loam soil that does not “bake” or form a crust on the surface to any serious extent after an irrigation. Grain crops on a heavier soil that “bakes” badly may not respond as well to early irrigation.

Stage of Plant Growth when Irrigation was most Effective

When but one irrigation was given, there was little difference in the average yields whether this was applied in the three-leaf, five-leaf or shot-blade stages. If the first irrigation was postponed until the flowering stage, the yields were seriously reduced in the drier years as the plants were materially injured by drouth before the water was applied. A first application of water as late as the flowering stage was beneficial, however, and gave an increased yield over the plots receiving no irrigation in five years out of six on the wheat following cultivated crop, and in four years out of five on the wheat following wheat.

When two irrigations were given, the best average yields were secured from the wheat following cultivated crop when these were applied in the previous fall and in the flowering stage. The wheat following wheat gave the best yields when irrigated at the five-leaf and flowering stages.

Number of Irrigations Required

The maximum average yield was obtained with four irrigations on the wheat following cultivated crop and with three irrigations on wheat following wheat. However, the increase in yields with the greater number of irrigations over that received from one or two was not sufficient nor constant enough from year to year to make the increase significant.



Wheat irrigated soon after coming up. Note the vigorous growth of straw and large heads. The usually accepted idea that irrigating wheat before the plants are large enough to shade the ground reduces yields was not substantiated in these experiments as each year high yields were secured from this early irrigation.

Suggested Irrigation Practice for Wheat

The results of these tests and a study of field irrigation in southern Alberta for the past twenty-five years lead to the conclusion that, on medium and heavy soils, one irrigation, applied in the previous fall or in the spring or early summer, before the crop is seriously in need of water, will produce a good crop in the years of average rainfall. If May and June are dry months, a second application of water, at the heading to flowering stage, may be required. On soil that is light or low in fertility, three irrigations may be necessary in drier years.

Undoubtedly the most important item for the irrigation farmer to bear in mind in considering his irrigation practice for wheat is to apply the first irrigation before the crop shows signs of needing water. It seems advisable to irrigate as much of the grain land as possible in the previous fall, and as soon as seeding is finished in the spring to ditch the fields that were not fall-irrigated and start irrigating early enough so that the first irrigation will be completed before any of the grain is injured from lack of water.

IRRIGATION OF ALFALFA

Of all the factors contributing to the success of irrigation farming, the introduction of alfalfa as a forage and rotation crop is perhaps the greatest. As alfalfa is an important crop in almost all localities where irrigation water is used, it is only to be expected that numerous investigators have attempted to determine satisfactory irrigation practices for this crop. There seems to be a general agreement in the findings of most of the investigators that alfalfa requires a comparatively constant soil-moisture supply throughout the season, necessitating several irrigations where rainfall is light.

Review of Literature on Irrigation of Alfalfa

Working under the different conditions encountered in various stations of the Canadian and American West, investigators of the best number and time of irrigations have arrived at different final recommendations. At Brooks, Alberta, Snelson (37) obtained the greatest yield of alfalfa from five six-inch irrigations, although six four-inch irrigations gave almost the same yield. In New Mexico, Bloodgood and Curry (6) found ten irrigations necessary for maximum yields, while farther north in the lower Snake River Valley of Idaho, Bark (2) reported five irrigations as the general use. Beckett and Robertson (5) received maximum yields from four nine-inch irrigations on the Davis Farm, California, and another group of workers in the same state (1) recommends that alfalfa planted on very open or impervious soil should be irrigated more than once between cuttings.

Knight and Hardman (26), in Nevada, secured the greatest yields from the maximum application of water, 81 acre-inches per acre. Almost as good yields were obtained with 66 inches applied in eleven six-inch irrigations.

Sometime earlier, Knight (24) reported the use of 102 inches of water in the season on a gravelly soil, while on a sandy clay soil with clay subsoil 36 inches was sufficient for alfalfa. In the same bulletin, he reported yields of from 6.06 tons to 6.63 tons of alfalfa hay per acre when the crop was irrigated so that the plants were never allowed to show signs of needing water, 5.61 to 5.64 tons when plants showed need of water by dark green colour of foliage before being irrigated, and 3.98 to 5.18 tons when plants showed need of water by dark green colouring and drooping of leaves when irrigated.

For Arizona conditions, Smith (36) recommends irrigating alfalfa when two-thirds grown, but not just after cutting.

Widtsoe and Merrill (48) found that it made little difference on the yield of alfalfa at the Utah Station whether water was applied just before or just after cutting the hay crop. Widtsoe (44) considers that it is sufficient under conditions of deep soil and moderate evaporation to give the crop one irrigation for each cutting; two or three light irrigations for each cutting, he does not think objectionable. Regarding fall irrigation he states: "If fall and winter rainfall is insufficient to saturate the soil, fall or winter irrigation, especially if the winters are mild and open, has been found quite satisfactory."

In 1899, King (23) recommended two irrigations for each crop of alfalfa although he states that the usual practice at that time was to give but one irrigation for each crop. Etcheverry (9) states: "When the alfalfa has established a well-developed root system the common practice on retentive soils is to apply one irrigation either before or after cutting." He also says that "the number of irrigations per year for alfalfa ranges from four in Montana to twelve in parts of California and Arizona."

Application of Water to Alfalfa at Lethbridge

In these experiments alfalfa received from one to five irrigations as shown in the following schedule:—

A. One irrigation—

1. Previous fall.
2. Early May.
3. Plants of first crop 12 inches high.
4. Ten days before cutting first crop.
5. Immediately after cutting first crop.

B. Two irrigations—

1. Previous fall and first crop 12 inches high.
2. Previous fall and before cutting first crop.
3. Previous fall and after cutting first crop.
4. Early May and first crop 12 inches high.
5. Early May and before cutting first crop.
6. Early May and after cutting first crop.

C. Three irrigations—

1. Previous fall, first crop 12 inches high, and after cutting first crop.
2. Early May, first crop 12 inches high, and after cutting first crop.

D. Four irrigations—

1. Early May, first crop 12 inches high, after cutting first crop, and second crop 12 inches high.

E. Five irrigations—

1. Previous fall, early May, first crop 12 inches high, after cutting first crop, and second crop 12 inches high.

F. When crop appeared to need an irrigation.

One series of plots was left unirrigated as a check.

Yields of Alfalfa Hay Harvested

On the plots reported, two crops of alfalfa hay were secured each year. The alfalfa was cut when the plants were from one-half to three-fourths in bloom, raked up as it was cut, and weighed in the green state. A quantity of the green plants was immediately run through a chopper, duplicate two-pound samples of the cut material secured, and the dry matter determined by drying to constant weight at 100° C. The total dry matter produced on each plot was determined and 10 per cent arbitrarily added to this weight to convert it to a hay equivalent. Several tests made of alfalfa hay in the stacks at the station showed well-cured hay to contain approximately 10 per cent of moisture.

The computed pounds of hay per acre obtained from each irrigation treatment for the five years that the test has been under way are shown in table 10. The five-year average is also given.

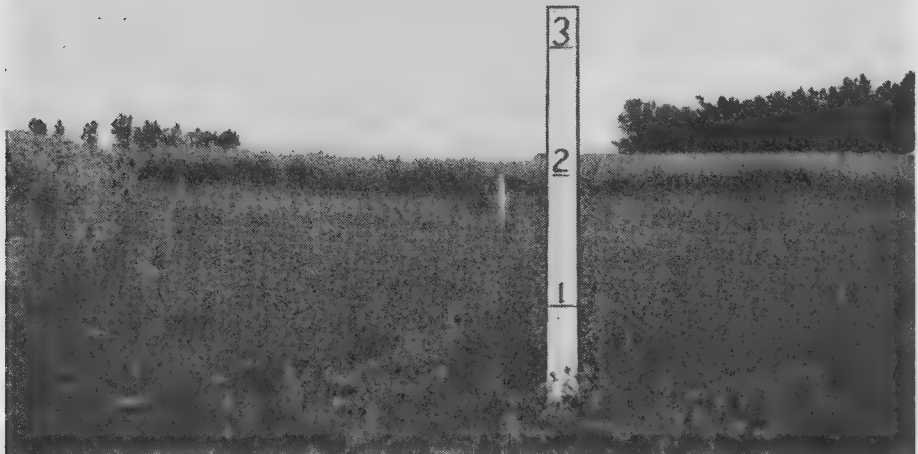
TABLE 8.—Yields in Pounds per Acre of Alfalfa, Irrigated at Different Stages of Growth.
1923-1927, with 5-year averages

Number of irrigations	Stages of plant growth when water was applied	Five-year average	1923	1924	1925	1926	1927
0	Dry.....	3,108	4,200	3,920	780	2,600	4,040
1	Fall.....	6,608	5,420	4,880	8,220	7,840	6,680
1	E.M.....	6,908	5,700	5,380	8,260	8,760	6,440
1	12" H.....	5,984	5,880	6,000	6,760	5,480	5,800
1	B.I.C.....	4,908	6,640	4,080	3,120	4,920	5,780
1	A.I.C.....	4,964	5,680	5,460	3,480	4,040	6,160
2	F., 12" H.....	6,756	6,440	5,160	8,100	7,640	6,440
2	F., B.I.C.....	6,336	5,620	5,560	6,220	8,160	6,120
2	F., A.I.C.....	6,456	5,800	5,380	6,800	7,280	7,020
2	E.M., 12" H.....	6,844	5,700	5,740	7,820	9,040	5,920
2	E.M., B.I.C.....	6,548	5,920	4,860	7,120	7,560	7,280
2	E.M., A.I.C.....	6,612	6,100	7,040	5,800	8,600	5,520
3	F., 12" H., A.I.C.....	7,268	5,840	6,900	7,880	9,040	6,680
3	E.M., 12" H., A.I.C.....	7,396	5,800	7,180	8,460	8,880	6,660
4	E.M., 12" H., A.I.C., 2nd 12" H.....	6,908	6,940	6,300	7,940	7,580	5,780
5	F., E.M., 12" H., A.I.C.....	7,468	7,320	6,100	9,740	7,520	6,660
.....	Crop Needs.....	7,324	5,980	4,820	8,340	9,840	7,640

Abbreviations used: F.—Fall, E.M.—Early May, 12" H.—12" High, B.I.C.—Before 1st Cutting, A.I.C.—After 1st Cutting.

Stage of Plant Growth when Irrigation was Most Effective

The data in Table 8 show that, where only one irrigation was given, the greatest average yield for the five years was obtained when this was applied in early May. The yield from a fall irrigation was almost as good as the spring irrigation, the difference in yield not being significant. Postponing the irrigation until plants were 12 inches high decreased the average yield about one-half ton per acre. When the first irrigation was delayed until just before or just after the first crop was cut, the average yield was reduced almost exactly one ton per acre. The increased yields obtained from the earlier irrigations are



Alfalfa just before cutting the first crop. Plots in the foreground were permitted to become too dry before water was applied and a poor crop resulted. The plot in the background was irrigated early in May and produced a heavy yield.

easily understood and are important in formulating an irrigation practice for alfalfa. When the irrigation was postponed in the spring until the plants suffered for water, the yield of the first cutting of hay was materially reduced. Where heavy early May rains are received as was the case in 1923 and 1927, early irrigations may not be of benefit but if May is a dry month, as it has been in sixteen of the twenty-six years that records are available at Lethbridge, a May irrigation appears to be essential if a heavy first cutting is to be expected. This is in harmony with the results obtained by Knight (24) in Nevada, where yields were depressed when the plants were allowed to suffer at all for water.

IRRIGATION BEFORE OR AFTER CUTTING.—The question of the relative merits of irrigating the alfalfa field just before or just after cutting the first crop of hay is often discussed. Three separate comparisons are possible each year of plots irrigated before, and plots irrigated after cutting. One comparison is of plots, irrigated at the cutting stage only, one of plots irrigated in the previous fall and at cutting and one in the spring and at cutting. In each set the five-year average yield was slightly greater on the plots irrigated after cutting than on those irrigated before cutting. These differences are so small, however, that they are not significant. An examination of the yields for the individual years shows a higher yield for each set of plots irrigated after cutting in three years and a higher yield for the irrigations before cutting in two years. The results of this experiment seem to agree with the findings of Widtsoe and Merrill (48)—that it makes little difference in yield whether irrigations are applied just before or just after cutting.

FALL VERSUS SPRING IRRIGATION.—Five comparisons between fall and spring irrigations are shown in table 8, one with only the fall irrigation, three with one additional irrigation and one with two additional irrigations. The five-year average production was greater on each set of plots irrigated in the spring than on those irrigated in the fall. The only difference of yield great enough and constant enough from year to year to be significant, was on the plots receiving but one irrigation. The five-year average yield of hay on the plots receiving one irrigation in the spring was 300 pounds more than the yields on the plots irrigated only in the fall. Not only was the average yield greater, but in four years out of five, the yield was more with spring irrigation. The "wet" year of 1927 was the one year when the plots irrigated only in the fall produced more hay than those irrigated in the spring.

The results of these tests, and especially the observed condition of the crops as they were growing, and the soil moisture studies, indicate that a fall irrigation is not as effective in producing a crop of hay the following year as is an irrigation in the spring. This seems to be due to there being less water available for the crop from a fall irrigation, due to losses between the time when the water is applied in the fall and when growth starts in the spring.

When additional water was applied during the growing season, before plant growth was checked by a need of water, the yields obtained were as high on the fall-irrigated plots as on those irrigated in the spring. While an early spring irrigation gave better results than a fall irrigation, if the spring irrigation was postponed until the plants were 12 inches high, the fall irrigation was superior.

The results of these tests would suggest the advisability of irrigating enough of the alfalfa field in the fall so that the balance could be covered with water in the first half of May.

Number of Irrigations Required for Alfalfa

Four irrigations gave the highest five-year average yield of alfalfa, followed closely, even in dry years, by three irrigations, one applied in early May, another when the plants were 12 inches high, and the third immediately after the first crop was harvested. In the drier years, two irrigations were not enough to produce heavy yields, but in the seasons of medium rainfall, two were sufficient.

Suggested Irrigation Practice for Alfalfa

All of the alfalfa should be irrigated in the fall or early May of the following spring, unless an unusually wet fall or wet spring is experienced. If May is dry, another application of water when the crop is about 12 inches high is desirable. If the season continues dry, a third application of water before or just after cutting may be required.

IRRIGATION OF POTATOES

Light to medium-textured, well-drained soils in districts suitable for irrigation are usually admirably adapted to the growth of potatoes. Most of the irrigated lands of Alberta will produce good crops of potatoes; in fact it is doubtful if there is an area anywhere on the continent where better yields can be secured, or potatoes of higher quality grown.

Review of Literature on Irrigation of Potatoes

With one or two exceptions, the findings of investigators have been that potatoes require several irrigations, especially after tubers start to form on the stolons of the plants.

The opinions of two Alberta investigators are available on the best irrigation practice for potatoes. Four three-inch irrigations at Brooks and five three-inch irrigations at Ronalane produced the maximum yields of potatoes, according to Snelson (37). Fairfield's recommendation (11) is that: "If possible the first irrigation should not only be very light, but it should not be given until the small potatoes are set and are perhaps the size of peas. This stage is usually about the time the first blooms appear."

Irrigation workers in the United States have recommended a wide variance of irrigation practice for potatoes. Four reports from Utah are available. Widtsoe and Merrill (48) secured the best yields with six irrigations, but four heavier irrigations gave almost as good a yield. Widtsoe (45) states: "Potatoes need a good supply of water in the soil at planting time . . . Little water is needed by potatoes during the first period of growth, providing there is a plentiful supply in the soil at the time of planting . . . It is seldom advisable to irrigate oftener than every two weeks, and every three or four weeks frequently gives satisfactory results. Irrigation should cease about the middle of August, leaving about sixty days for the ripening of the potatoes." Working with Stewart, Widtsoe (49) found the percentage of water in the tubers little if any affected by the application of too much water. Two other experimentalists in this state, Harris and Pittman (17) found that practice of watering potatoes before they were up so ruinous that it was dropped from their tests. They also found that applying all the water very early or very late in the season was undesirable. Their best yields were obtained from moderate irrigations given at regular intervals of 7 and 14 days during the dry summer season, beginning when the plants were six inches high and discontinuing about a month before harvest.

Investigators in other western states advance different counsels. In New Mexico, Bloodgood and Curry (6) obtained the highest yields from four five-inch irrigations distributed over a period of three months. Bark (4) found five or six irrigations necessary for maximum yields in Southern Idaho, while in Nevada, Knight and Hardman (26) obtained the highest yields from five three-inch irrigations given when the plants showed a tendency to wilt or before wilting was noticeable. Working as early as 1892, Buffum (7) explained the effect of early irrigation of potatoes in Wyoming thus: "When irrigated immediately before setting, a greater number of potatoes will be formed than the plant can

properly support, few of them becoming large enough for market. When the tubers are allowed to form first and irrigated afterwards, fewer potatoes will form in each hill but a larger crop of marketable potatoes is the result." Etcheverry (9), generalizing on the number of irrigations required for potatoes, says, "The number of irrigations will vary from two to four for ordinary sandy loam, and from four to six light irrigations for a porous sandy soil or shallow soil."

Application of Water to Potatoes at Lethbridge

In these experiments potatoes received from one to six irrigations at different stages of plant growth, as shown in the following schedule:—

A. One irrigation:—

1. Previous fall.
2. Plants half-grown.
3. Plants starting to bloom.
4. Plants in full-bloom.
5. Ten days after full-bloom.

B. Two irrigations:—

1. Previous fall and starting to bloom.
2. Previous fall and full-bloom.
3. Starting to bloom and full-bloom.
4. Full-bloom and ten days later.

C. Three irrigations:—

1. Starting to bloom and at intervals of ten days.
2. Starting to bloom and at intervals of twenty days.

D. Four irrigations:—

1. Plants half-grown, starting to bloom, and at intervals of ten days.
2. Starting to bloom and at intervals of ten days.

E. Five irrigations:—

1. Starting to bloom and at intervals of ten days.

F. Six irrigations:—

1. Starting to bloom and at intervals of ten days.

One series of plots was left unirrigated as a check.

Yields of Potatoes

The potatoes were harvested early in October and were well ripened at the time of harvest. All potatoes badly misshapen and those weighing under approximately three ounces were classed as unmarketable. The marketable and unmarketable tubers were weighed separately.

In table 9 is shown the total yield of marketable and unmarketable tubers obtained from each irrigation treatment for the five years of 1923 to 1927. Table 10 contains the yield data of marketable potatoes, and five-year averages are also given in each table.

TABLE 9.—Total yields of Marketable and Unmarketable Potatoes in Pounds per Acre, Irrigated at Different Stages of Growth, 1923-1927, with five-year averages

Number of irrigations	First irrigation	Subsequent irrigations	Five-year average	1923	1924	1925	1926	1927
0	Dry.....		15,292	10,280	20,490	8,610	12,512	24,567
1	Fall.....		20,749	20,280	26,200	18,000	14,696	24,567
1	Half-grown.....		18,026	15,940	17,340	16,970	13,923	25,957
1	S.B.....		20,400	20,263	17,460	20,850	17,176	26,251
1	F.B.....		20,255	17,140	20,180	22,260	13,741	27,953
1	10 d.a.F.B.....		21,163	20,300	23,820	19,910	13,786	27,999
2	Fall.....	S.B.	22,959	20,270	24,070	23,230	20,976	26,251
2	Fall.....	F.B.	22,510	19,210	23,130	25,970	16,289	27,953
2	S.B.....	F.B.	22,765	18,310	20,700	25,990	19,156	29,671
2	F.B.....	in 10 days.....	22,439	21,580	24,470	25,920	14,560	25,664
3	S.B.....	ev. 10 days.....	22,938	19,230	22,350	25,870	22,750	24,492
3	S.B.....	ev. 20 days.....	24,201	17,160	26,420	30,200	17,790	29,436
4	S.B.....	ev. 10 days.....	22,726	18,980	17,650	30,120	22,340	24,538
4	Half-grown.....	F.B. and ev. 10 days..	20,389	18,080	17,340	25,820	15,062	25,645
5	S.B.....	ev. 10 days.....	25,109	19,290	21,800	33,450	22,340	28,667
6	S.B.....	ev. 10 days.....	24,347	20,210	20,130	32,790	21,703	26,902

TABLE 10.—Yield of Marketable Potatoes in Pounds per Acre, Irrigated at Different Stages of Growth, 1923-1927, with five-year averages

Number of irrigations	First irrigation	Subsequent irrigations	Five-year averages	1923	1924	1925	1926	1927
0	Dry.....		14,055	9,010	19,380	7,260	11,648	22,975
1	Fall.....		19,540	18,600	25,090	16,840	14,196	22,975
1	Half-grown.....		16,956	14,560	16,440	15,900	13,058	24,820
1	S.B.....		19,419	18,490	16,680	20,180	16,744	25,000
1	F.B.....		19,040	15,240	18,920	21,460	13,058	26,520
1	10 d.a.F.B.....		19,435	18,650	22,320	18,380	12,467	25,360
2	Fall.....	S.B.	21,516	18,740	22,900	21,010	19,929	25,000
2	Fall.....	F.B.	21,253	17,130	22,200	24,810	15,606	26,520
2	S.B.....	F.B.	21,014	16,780	18,960	24,210	18,518	26,600
2	F.B.....	in 10 days.....	20,943	19,450	22,570	25,110	14,105	23,480
3	S.B.....	ev. 10 days.....	20,817	16,970	19,790	24,930	21,476	20,920
3	S.B.....	ev. 20 days.....	22,559	14,750	25,140	28,680	16,744	27,480
4	S.B.....	ev. 10 days.....	20,409	16,060	15,770	26,840	20,976	22,400
4	Half-grown.....	F.B. and ev. 10 days..	18,830	16,270	16,080	24,050	13,970	23,780
5	S.B.....	ev. 10 days.....	23,171	16,820	20,180	31,920	20,976	25,960
6	S.B.....	ev. 10 days.....	22,254	17,430	18,600	30,500	20,338	24,400

Stage of Plant Growth when Irrigation was Most Effective for Potatoes

FALL IRRIGATION.—An irrigation in the previous fall gave results about equal to an irrigation applied when the plants were starting to bloom and decidedly better than irrigating when the plants were but half-grown.

WHEN THE FIRST AND SUBSEQUENT IRRIGATIONS GAVE BEST RESULTS.—The lowest average yield from any plot-series irrigated but once was obtained from plots receiving water when the plants were half-grown. Of the plots irrigated more than once, those receiving the first irrigation when the plants were half-grown gave the smallest yield. The lower yields from both sets of the earlier-irrigated plots supported the statements of Fairfield (11) and Buffum (7), that it is not advisable to irrigate potatoes before the tubers are set (about the starting-bloom stage). Buffum suggests that earlier irrigations are undesirable because the application of water before the setting of the tubers stimulates the vines to set more tubers than they can support. This results in a smaller number of large potatoes and an increased number of small potatoes. This view is not

supported by the results of these tests as the percentage of marketable potatoes was as high on the earlier-irrigated plots as those receiving the first application of water some time later.

There was little difference in the total yields when the first application of water was made in the starting-bloom, full-bloom, or ten days after full-bloom periods except in 1926. In that year the potatoes not irrigated until the full-bloom stage or later were so checked in their growth that their yields were from one to two tons per acre less than the yields secured from the plots irrigated in the starting-bloom period. The percentage of marketable potatoes was also less with the later irrigations.

When two irrigations were given it seemed to make little difference in yields whether these were applied in the fall and starting-bloom, in the fall and full-bloom, or in the starting-bloom and full-bloom periods. The irrigations in the fall and at the full-bloom periods gave the highest percentages of marketable potatoes.

With three irrigations, better yields and higher percentages of marketable tubers were secured when the irrigations were applied in the starting-bloom stage and at intervals of twenty days than when applied in the starting-bloom stage and at intervals of ten days.

Number of Irrigations Required for Potatoes

Two irrigations gave a yield of about one ton per acre more marketable potatoes than was secured from one irrigation. Three irrigations—the first in the starting-bloom period and the others at intervals of twenty days—gave a yield of one-half ton per acre more than was secured with two irrigations.

The highest total yield of marketable and unmarketable potatoes was secured from five irrigations. The yield of marketable potatoes was but little better, however, than from three irrigations. Six irrigations gave a lower yield than five.

Relation of Irrigation Practice to Percentage of Marketable Potatoes

The lowest five-year average percentage of marketable potatoes was on the plots receiving no irrigation, while there was a uniformly higher percentage with one or two irrigations than with three or more. Permitting the plants to become too dry or supplying an excessive amount of water resulted in more small potatoes.

Effect of Irrigation Treatment on Quality of Potatoes

Some prejudice has existed in the minds of many people against potatoes grown on irrigated land, as it is thought that the application of water has a tendency to increase the water content of the potatoes and make them "soggy". As already quoted, Widtsoe and Stewart (49) found that the water content of ripe potatoes was not increased by applying too much water.

In 1924 and 1925, the Department of Household Economics of the University of Alberta, under the direction of Miss Mable Patrick, co-operated in the experiment with potatoes by making laboratory and cooking tests of samples of uniform tubers of medium size from each irrigation treatment. Table 11 contains the quality scores of the potatoes submitted for tests for the two years as reported by Miss Patrick. In 1924, only one sample was sent from the duplicate plots receiving the same treatment, but in 1925, tests were made of potatoes from each plot. The two scores shown for each treatment in 1925 are for the duplicate plots.

TABLE 11.—Effect of Irrigation Practice on the Quality of Potatoes, 1924 and 1925

Number of irrigations in season	Stage of plant growth when first irrigated	Time of, or intervals between, subsequent irrigations	Average quality score	
			1924	1925
None			86.5	53.4
None				72.0
1	Half-grown.....		77.8	67.6
1	Half-grown.....			62.6
1	Starting-bloom.....		87.5	78.6
1	Starting-bloom.....			64.2
1	Full-bloom.....		67.0	75.8
1	Full-bloom.....			72.0
1	Fall.....		69.5	66.2
1	Fall.....			72.4
1	10 days after f.b.....		69.5	62.4
1	10 days after f.b.....			70.2
2	Fall.....	Starting-bloom.....	69.5	73.0
2	Fall.....	Starting-bloom.....		79.0
2	Fall.....	Full-bloom.....	66.3	67.6
2	Fall.....	Full-bloom.....		68.4
2	Starting-bloom.....	10 days.....	69.5	70.6
2	Starting-bloom.....	10 days.....		75.6
2	Full-bloom.....	10 days.....	67.0	67.2
2	Full-bloom.....	10 days.....		73.0
3	Starting-bloom.....	10 days.....	58.5	70.8
3	Starting-bloom.....	10 days.....		72.2
3	Starting-bloom.....	20 days.....	68.8	74.2
3	Starting-bloom.....	20 days.....		59.6
4	Half-grown.....	10 days.....	77.5	76.6
4	Half-grown.....	10 days.....		73.4
4	Starting-bloom.....	10 days.....	77.3	76.0
4	Starting-bloom.....	10 days.....		68.2
5	Starting-bloom.....	10 days.....	61.5	83.5
5	Starting-bloom.....	10 days.....		78.0
6	Starting-bloom.....	10 days.....	82.5	66.6
6	Starting-bloom.....	10 days.....		59.6

There was no uniformity of quality for the same treatment in different years nor for duplicate treatments in the same year (table 11). Nor was there any uniform improvement in quality when the number of irrigations was increased or decreased. About the only inference that could be drawn from these data was that the irrigation treatment did not affect the reported quality factors sufficiently to overcome individual differences in the tubers.

In addition to the quality tests made at the University of Alberta, potatoes of uniform appearance from various irrigation treatments were numbered and given to families residing on the Lethbridge Station. Steaming, boiling and baking tests were made by the housewives of these families. Their reports agreed with the laboratory tests reported—that the irrigation treatment had not affected the quality of the potatoes to a noticeable extent.

Each year at harvest the tubers were carefully observed for scab, rhizoctonia sclerotia, misshapen potatoes, secondary growths, and other observable characters that might affect the quality of the potatoes. As only certified and treated seed were used, and as the potatoes were planted each year on land that had never before produced a crop of potatoes, they were comparatively free from scab or rhizoctonia sclerotia, but there was no apparent difference in the disease effects on the crops of various irrigation treatments.

Some second growths, resulting in "knotty" potatoes, were observed in the drier years when the first irrigation was delayed until ten days after full bloom. This condition appeared to have been caused by the potatoes starting to ripen due to lack of water and then when the water was applied, sprouting into new growths at the eyes of the partially ripened tubers.

Another treatment that had a noticeable effect on the appearance of the potatoes was the application of an excessive number of irrigations. Where more than four irrigations were applied, the lenticels became enlarged, forming white spots on the skins of many of the tubers. This condition was apparent on the plots receiving as few as four irrigations in the wet season of 1927.

Suggested Irrigation Practice for Potatoes

These experiments would indicate that a good crop of potatoes can usually be raised on fertile, medium-textured soils without irrigation during the growing season, if the land has been irrigated the previous fall. The yields were increased in the drier years, however, by irrigating again soon after the plants started to bloom and by giving two more irrigations at intervals of twenty days.

It does not appear to be a good practice to irrigate before the plants start to bloom unless the soil is so dry as to retard growth.

IRRIGATION OF SUGAR BEETS

The Canadian Sugar Factories, Limited, erected a factory for the refining of beet sugar at Raymond, Alberta, in 1925, so sugar beets were included in the irrigation tests that year.

Review of Literature

The sugar beet has become an important crop in most of the irrigated sections of the United States, and its irrigation has been the subject of investigations in a number of localities.

From different parts of the irrigated state of Utah come a number of recommended practices. Widtsoe and Merrill (48) found, in tests at the Utah Station, that the greater the number of irrigations up to six, the larger were the yields of sugar beets. When six-inch irrigations were applied bi-monthly to a total of six, the best yields were secured. In the Sevier Valley, Utah, which has an average annual precipitation of only 8.34 inches, Israelson and Windsor (19) reported that four or five irrigations were necessary. Harris (14), from five years' experiments in Utah, found that where but one irrigation was given, it was most effective when applied at the time the beets averaged about two inches in diameter. When the water was applied at the proper time, two or three irrigations of five inches each gave as good results as where more water was applied. Maximum yields were secured from three irrigations applied just before thinning, when the beets averaged two inches in diameter, and when they were nearly ripe. The yields were almost as good when the irrigation before thinning was not given.

The various counsels of other experimentalists originate in the different conditions experienced in other western states. Working in Oregon, Powers (32) obtained maximum yields with one irrigation in three years out of five. In the other two years, two irrigations gave the best yields. In Nevada, Knight and Hardman (26) obtained the best yields from six three-inch irrigations. Roeding (34), a Colorado worker, secured higher yield per acre from 11.3 inches of water applied in two irrigations than from larger quantities in three or four irrigations.

Knorr (27) found that the yield of sugar beets on land receiving a fall irrigation and three growing season irrigations was 1.6 tons greater than when the land received the three summer irrigations without an application of water in the fall. He secured best results when the beets were so irrigated as to keep the plant in good condition from the time of thinning to about three weeks before harvest.

Nuckols and Currier (31), in recommending an irrigation practice for the Billings region of Montana, state that "Beets should not be irrigated until they are too large to cultivate and the leaves have spread out so that they will cover the ground and shade it, so that the heavy crusts will not form in the furrows where the water has run. These beets are usually ready to irrigate about July 15 to 25." After irrigation is begun, they state that it is usually necessary to continue to irrigate every ten to twenty days from the time of the first irrigation until about the first of September.

Application of Water to Sugar Beets at Lethbridge

From one to five irrigations were applied to sugar beets in these experiments, as shown in the following schedule:—

A. One irrigation:—

1. Previous fall.
2. Immediately after thinning.
3. Six weeks after thinning.

B. Two irrigations:—

1. Previous fall and eight weeks after thinning.
2. After seeding, but before plants were up, and eight weeks after thinning.
3. Five weeks after thinning and four weeks later.
4. Five weeks after thinning and six weeks later.

C. Three irrigations:—

1. Previous fall, five weeks after thinning and four weeks later.

D. Five irrigations:—

1. Previous fall, two weeks after thinning, and at intervals of four weeks, three weeks and two weeks.

One set of plots was left unirrigated as a check.

Yield of Beets

The germination of the beets was very poor in 1925, resulting in inferior stands, so the yields for that year are not reported in table 12 where the yields for the years 1926 and 1927, and the average for the two years are presented.

TABLE 12.—Yields in Pounds per Acre of Sugar Beets, Irrigated at Different Stages of Growth. 1926 and 1927, with two-year Averages

Number of irrigations	Stages of plant growth, when irrigated	Two-year average	1926	1927
0	Dry.....	32,600	21,600	43,600
1	Fall.....	33,100	26,800	39,400
1	Immediately a.th.....	30,600	27,200	34,000
1	6 w.a.th.....	31,100	24,000	38,200
2	Irrigated up, 8 w.a.th.....	28,200	28,000	29,200
2	5 w.a.th., 4 w.l.....	33,000	25,400	40,600
2	5 w.a.th., 6 w.l.....	34,600	28,600	40,600
2	Fall, 8 w.a.th.....	30,000	22,400	37,600
3	Fall, 5 w.a.th., 4 w.l.....	35,300	26,200	44,400
5	Fall, 2 w.a.th., 4 w.l., 3 w.l., 2 w.l.....	35,600	26,800	44,400

Abbreviations used: w. a. th.—weeks after thinning. w. l.—weeks later.

As but two years' yield data are available for sugar beets, very little can be said of the effects of the irrigation treatment on the yield of beets. It was quite evident, however, in observing the crop of 1925 that the beets not irrigated until after July 24 (which was six weeks after thinning) were seriously injured by drouth. In 1926, following the wet fall of 1925, an irrigation any

time up to eight weeks after thinning prevented the plants from being retarded in their growth by lack of water. One irrigation appeared to be all that was required in that year. The precipitation of 1927 seemed to provide all the water needed by the beets in that year since no increases in yields were obtained by irrigating.

Sugar Content of Beets

The Canadian Sugar Factories Limited have kindly co-operated in the sugar beet tests by determining the sugar content of beets selected at random from each plot. Six beets were secured for sugar tests—two large beets, two of medium size, and two small. The sugar content data of 1925 are included in table 13 along with those of 1926 and 1927 as the poor stands, which precluded the use of the yield data for 1925, may not have influenced the sugar content of the beets. Three irrigation treatments are reported for 1925 that are not shown for 1926 and 1927. These are plots that were fall-irrigated for the crops of 1926 and 1927, but were not fall-irrigated in 1924 for the 1925 crop. In 1926, samples of beets from the plots irrigated the previous fall and those irrigated six weeks after thinning were lost in transit to the sugar factory, so the sugar content data for those irrigation treatments in 1926 are not available.

TABLE 13.—Percentage of Sugar in Sugar Beets Irrigated at Different Stages of Growth.

Number of irrigations	Stages of plant growth when irrigated	Three-year average 1925-1926-1927	Two-year average 1926-1927	1925	1926	1927
0	Dry.....	17.5	18.2	16.1	17.9	18.6
1	Previous Fall.....					16.5
1	Immediately a. th.....	17.3	17.8	16.3	18.0	17.5
1	6 w. a. th.....			17.2		17.6
1	8 w. a. th.....			15.1		
1	Before harvest.....			15.1		
2	5 w. a. th., 4 w. l.....	16.5	16.6	16.1	16.5	16.8
2	5 w. a. th., 6 w. l.....	17.1	17.3	16.7	17.3	17.3
2	Previous fall, 8 w. a. th.....		17.2		17.3	17.0
2	Irrigated up, 8 w. a. th.....		17.8		18.0	17.7
3	Previous fall, 5 w. a. th.....		17.6		17.6	17.7
5	Previous fall, 2 w.a.th., 4 w.l., 3 w.l., 2 w.l.....		18.0		17.4	18.5
4	2 w. a. th., 4 w. l., 3 w. l., 2 w. l.....			17.1		

Abbreviations used: w. a. th.—weeks after thinning. w. l.—weeks later.

While the data given on the sugar content of beets from different irrigations are meagre, there are two interesting features connected therewith:—

1. The beets that were not irrigated in the season of 1925 until they had started to “burn” were decidedly low in sugar content.

2. The beets irrigated heavily were high in sugar content in all three years.

It is thought by some sugar beet experts that the sugar content is materially reduced if the beets are allowed to burn and are then irrigated. The low sugar content obtained in 1925 from beets irrigated after they had been seriously injured by drought seems to corroborate this opinion. This is also supported by the work of Harris (14), who obtained the lowest sugar content when water was withheld from the beets until they were approaching maturity. He does not state whether or not the beets “burned” before irrigating, but this is suggested by the low yields.

The high sugar content of beets receiving the greatest number of irrigations is in direct opposition to the opinion of many farmers who believe that irrigating decreases the sugar content, but is in accord with the results obtained by Harris (14).

IRRIGATION OF SUNFLOWERS

Sunflowers are only a minor crop under irrigation, and, undoubtedly for that reason, very little information is available regarding their water requirements. For Montana, Jensen (21) recommends irrigating before the plants show signs of wilting. He reports that three irrigations were required for sunflowers at the Huntley Experimental Farm in 1918. These were applied on July 9, August 2 and August 8. In 1919, five irrigations were given. Knight of Nevada (25) states that sunflowers should be irrigated like corn.

Application of Water to Sunflowers at Lethbridge

In formulating an irrigation practice for sunflowers, it was found impractical to specify a growth stage. The only distinguishing growth factor was height, and this could not be used as a guide after the plants reached a height of six inches, because growth was so rapid where conditions were favourable and because it varied so much on the plots receiving different treatments. For these reasons, definite intervals of time (after the plants were six inches high) were specified for the applications of water. The following schedule describes the program of irrigations:—

A. One irrigation:—

1. Previous fall.
2. Plants six inches high.
3. One week after plants were six inches high.
4. Two weeks after plants were six inches high.

B. Two irrigations:—

1. Previous fall and July 15.

C. Irrigations at definite intervals, the total number dependent on the earliness of the season:—

1. Plants six inches high, and every week until August 10 to 15.
2. Plants six inches high, and every two weeks until August 10 to 15.
3. Plants six inches high, and every three weeks until August 10 to 15.
4. Plants six inches high, and every four weeks until August 10 to 15.
5. Plants 6 inches high, and every three weeks until July 25.
6. Plants six inches high, and every three weeks until July 5.
7. Two weeks after six inches high and every three weeks until August 10 to 15.
8. Two weeks after six inches high and every three weeks until August 10 to 15.

D. When the crop appeared to be in need of an irrigation.

One set of plots was left unirrigated as a check.

Yield of Sunflowers

The sunflowers were cut for silage when the seeds were partly glazed. The green weights were secured immediately after cutting and are reported in table 14 for the various irrigation treatments for the two years of 1923 and 1924, together with the two-year average yields.

The experiments with sunflowers were discontinued after the second year as yield, cultural and feeding tests at the Station showed that sunflowers were not as good as corn for a silage crop on the irrigated lands of southern Alberta. It became evident, therefore, that sunflowers would not be as important a farm crop under irrigation as it was thought they would be when the irrigated experiment was started.

TABLE 14.—Yield of Sunflowers in Pounds per Acre (Green Weight) With Various Irrigation Treatments

Number of irrigations		Stage of plant growth or time when water was applied		Two-year average	1923	1924
1923	1924	First irrigation	Subsequent irrigations			
.....	.....	Dry.....	.....	25,715	31,680	19,750
1	1	Fall.....	.....	41,075	58,800	23,350
1	1	6 inches.....	.....	37,750	48,300	27,200
1	1	1 w.a. 6 inches.....	.....	31,350	43,000	19,700
1	1	2 w.a. 6 inches.....	.....	30,375	41,000	19,750
2	2	Fall.....	July 18.....	44,200	60,200	28,200
10	8	6 inches.....	Every week until August 10 to 15....	19,200	20,900	17,500
5	4	6 inches.....	Every two weeks until August 10 to 15.....	26,100	30,850	21,350
3	3	6 inches.....	Every three weeks until August 10 to 15.....	34,200	44,800	23,600
3	2	6 inches.....	Every three weeks until July 25....	35,250	46,650	23,850
2	2	6 inches.....	Every three weeks until July 5.....	32,075	40,900	23,250
3	2	6 inches.....	Every four weeks until August 10 to 15.....	35,200	46,900	23,500
3	2	2 w.a. 6 inches.....	Every three weeks until August 10 to 15.....	29,275	38,550	20,000
2	2	4 w.a. 6 inches.....	Every three weeks until August 10 to 15.....	28,075	38,150	18,000
1	1	When crop needed water.....	.....	29,325	40,900	17,750

Abbreviations used: 6 inches—Plants 6 inches high. w. a.—weeks after.

Fall Irrigation

In the two years that sunflowers were under test the best yields were obtained from an irrigation in the previous fall and another on July 18. An irrigation in the previous fall without the application of water during the growing season gave the second largest yield in 1923, but was exceeded or equalled in 1924 by all the plots irrigated when the plants were six inches high, except those receiving water every two weeks or every week.

Number of Irrigations Required for Sunflowers

The poorest yields were secured in both years from the plots irrigated every week. The plots irrigated every two weeks were decidedly better than those irrigated every week, but were much inferior to the plots receiving water at three-week intervals or less frequently. It was very evident, by the appearance of the growing crop and the yields secured, that sunflowers could not stand an excess of water and that irrigating as often as every two weeks was detrimental to the crop.

It was also noted that yields were reduced if the first irrigation was withheld until the plants started to wilt. An interesting feature observed, however, was that the sunflower plants, although badly wilted, would revive as soon as the water was applied, and make satisfactory (though retarded) growth. This is in accord with observations made by Matthews (28) at the Dominion Experimental Station, Scott, Saskatchewan, where he noted that the growth of sunflowers on dry land was very slow in the severest part of the drought period, but that they had the ability to revive with the August rains and have always produced a fair crop in the driest years.

Suggested Irrigation Practice for Sunflowers

It appears, from the limited data available, that fall irrigating is a good practice for sunflowers. If a fall irrigation has not been given and if the early spring season is dry, it seems advisable to irrigate the crop by the time the

plants are six inches high. It is doubtful if another irrigation will be required unless the season is unusually dry. If the plants show signs of wilting, however, they should be irrigated at once.

SOIL MOISTURE

Soil moisture studies were conducted in connection with the irrigation investigations, primarily to help determine if differences in crop behaviour from various irrigation treatments were due to water relationships of the soil and plant or to other causes. The data and discussions that follow, therefore, are concerned principally with these factors.

The soil moisture data from the sunflower and the sugar beet plots are not included, as these experiments have not been conducted for a long enough period to secure sufficient observations for making satisfactory deductions.

Review of Literature on Soil Moisture

Many investigators have studied the various phases of the soil moisture problem, but only the literature that bears directly on irrigation is referred to here.

The only report of work done under Alberta conditions is that of Snelson (31), who found that a silt loam soil had an available water-holding capacity of 22.63 inches for a six-foot depth, while sand had a water-holding capacity of 8.01 inches for the same depth.

Widtsoe and McLaughlin (46) conducted extensive soil moisture studies on a deep loam soil at the Utah Station, sampling the soil to a depth of eight feet. Some of their important findings were: 1. The maximum amount of water held by the soil under field conditions was about 24 per cent (on a dry basis) and the minimum amount was about 8 per cent except that the top foot of soil dried out to 5.64 per cent. 2. Irrigation was needed whenever the soil moisture fell below 12 per cent, varying to some extent with different crops. 3. When a practical irrigator declared irrigation to be necessary, the soil was found to contain about 13 per cent of water. 4. Different crops leave different percentages of water in the soil at time of harvesting. The rate of loss of soil water varies with the age of the crop. Less water is used during the early and late periods than during the middle one.

In later experiments in Utah, Israelson and West (20) found that, as a general rule, soils have the capacity to absorb from a half to one and a half inches of water to each foot-depth of soil that needs moistening, the actual capacity for a given soil depending on its texture and structure. They state that "sandy or gravelly soils retain the smaller amounts and clay loam soils retain the larger amounts." They also found that uncropped plots given 36 inches of water held one-third inch more per foot of soil one day after irrigating than was held by plots receiving 12 inches of water, also that a plot receiving 24 inches held one-fourth inch more water per foot of soil than the plot receiving 12 inches of water. Ten days after the irrigations were applied, however, each of the plots held the same amount of available water, namely about one and a half inches per foot in the upper six feet.

In California, Adams *et al* (1) found that the average quantity of water retained in the upper six feet of the lighter and more permeable soils was 0.92 inch for each foot-depth of soil, whereas the clay soils absorbed an average of only 0.37 inch per foot of soil. In the surface foot, however, the light soils retained 1.04 inches and the heavier soils 1.71 inches. The maximum quantities

retained per acre-foot, of soil per irrigation were 1.02 acre-inches for silt loams, with fine sandy subsoils, 0.75 acre-inch for the clay loams, and 0.49 acre-inch for the clays.

From field tests in Washington, Thom and Holtz (39) concluded that the depth to which field crops took moisture was: wheat—9 feet, oats—8½ feet, barley—8 feet, peas—6 feet, millet—5½ feet, corn—5 feet, and beans—5 feet. They state that “crops that took the soil moisture from the greatest depths also had the greatest water requirement.”

Total Water Used by Crops or Lost by Evaporation or Deep Percolation

In the Lethbridge experiments an approximation was made of the water used by the crops, together with that lost from the soil by evaporation and from the top six feet of soil by downward percolation. This approximation was made by determining the amount of water in the soil in the spring and at harvest, and measuring the water supplied by irrigation and precipitation during the season. The summation of the water in the soil in the spring (a), the water applied by irrigation (b), and precipitation (c), less the water in the soil at harvest (d), gave the total water (T) used by the crops (x), plus that evaporated from the soil (y), and lost by percolation below six feet (z).

$$a+b+c-d=x+y+z=T.$$

For convenience, “T” is called the total water used.

The data in table 15 give the total water used for wheat following a cultivated crop, in table 16 for wheat following a wheat crop, in table 17 for alfalfa, and in table 18 for potatoes.

Tables 19, 20, 21 and 22 are correlation tables of the total water used in relation to yields of the various crops; and Charts 1, 2 and 3 picture this relation graphically.

In analyzing the data on the water used by the crops, it must be remembered that the irrigation water was applied at different stages of growth, and that the crop yields were often influenced more by the time that the water was given than by the total amount available for the crop during the year. This is shown in table 15 by comparing the plots irrigated but once during the year. The plots not irrigated until the flowering stage had practically as much water available for plant use as did the plants irrigated at earlier stages of plant growth, but the yields were from two to three hundred pounds per acre less. The same condition is shown with alfalfa in table 16. The alfalfa not irrigated until just before or just after cutting the first crop had about the same water to use as crops irrigated earlier, but produced from a half to one ton of hay per acre less than was produced with earlier irrigations. With but one irrigation on potatoes, water applied when the plants were but half-grown and that applied ten days after the full-bloom period seemed to have less crop-producing power than the water applied in the starting-bloom or full-bloom period.

The frequency distribution of yields with different amounts of water available (tables 19 to 22) show the same differences in yields with similar amounts of available water.

It is evident, then, that any statement as to the amount of water required for crops under irrigation is of little value unless the time that the irrigation water is to be applied is specified.

TABLE 15.—Total Water Used by the Crop, Evaporated from the Soil and Percolated Below Six Feet With Wheat following a Cultivated Crop, Irrigated at Different Stages of Growth, 1923 to 1927 Inclusive, with Five-year Averages of Crop Yield, Total Water Used, and Yield per Acre-foot of Water

Number of irrigations	Stages of plant growth when irrigated	5-year average wheat yield in pounds		Total water used in acre-feet per acre					
		Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
0	Dry.....	2,281	2,304	0.99	1.00	0.98	0.99	0.68	1.31 ⁽¹⁾
1	F.....	2,446	2,005	1.22	1.12	1.47	1.14	1.14	1.24
1	3L.....	2,570	1,977	1.30	1.32	1.49	0.73	1.26	1.70
1	5L.....	2,530	1,860	1.36	1.48	1.34	1.33	1.05	1.59
1	S.B.....	2,670	1,920	1.39	1.39	1.36	1.61	1.22	1.37
1	Fl.....	2,381	1,764	1.35	1.29	1.37	1.30	1.20	1.58
	Crop needs.....	2,518	2,031	1.24	1.45	1.41	1.24	1.04	1.07
2	F., S.B.....	2,545	1,533	1.66	1.61	2.04	1.72	1.46	1.47
2	F., Fl.....	2,647	1,665	1.59	1.45	1.85	1.38	1.65	1.60
2	5L., Fl.....	2,497	1,460	1.71	1.63	1.81	1.85	1.72	1.56 ⁽¹⁾
2	S.B., Fl.....	2,600	1,520	1.71	1.78	1.66	1.80	1.56	1.77
3	F., S.B., Fl.....	2,615	1,414	1.85	1.74	2.33	1.69	1.86	1.63
3	5L., S.B., Fl.....	2,686	1,285	2.09	1.95	2.12	2.41	2.09	1.89
4	5L., S.B., Fl., S.D.....	2,707	1,162	2.33	2.40	2.49	2.56	2.38	1.80
4	F., 5L., S.B., Fl.....	2,552	1,146	2.21	2.13	2.80	2.15	2.32	1.63

(¹) In 1927, only these had samples in duplicate.

TABLE 16.—Total Water Used by the Crop, Evaporated from the Soil and Percolated below Six Feet with Wheat Following Wheat, Irrigated at Different Stages of Growth, 1923 to 1927, Inclusive, with Five-year Averages of Crop Yield, Total Water Used and Yield per Acre-foot of Water

Number of irrigations	Stages of plant growth when irrigated	5-year average wheat yields in pounds		Total water used by crop, evaporated and percolated					
		Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
1	Dry.....	1,793	1,907	0.94	1.02	0.84	1.06	0.87	0.92
1	F.....	2,272	1,535	1.48	1.99	1.56	0.79	1.44	1.64
1	3L.....	2,233	1,479	1.51	1.46	1.47	1.38	1.52	1.71
1	5L.....	2,390	1,927	1.24	1.27	1.19	1.06	1.45	1.22
1	S.B.....	2,360	1,857	1.27	1.20	1.31	1.34	1.29	1.21
1	Fl.....	2,050	1,723	1.19	1.16	1.28	1.08	1.30	1.15
1	Crop needs.....	2,240	1,750	1.28	1.38	1.22	1.25	1.30	1.24 ⁽¹⁾
2	F., S.B.....	2,090	1,282	1.63	1.43	2.19	1.25	1.86	1.42
2	F., Fl.....	2,071	1,319	1.57	1.35	1.99	1.25	1.75	1.50 ⁽¹⁾
2	3L., Fl.....						1.81	1.88	1.70
2	5L., Fl.....	2,328	1,464	1.59	1.73	1.77	2.06	1.79	1.62
2	S.B., Fl.....	1,976	1,156	1.71	1.76	1.90	1.62	1.73	1.53 ⁽¹⁾
3	F., S.B., Fl.....	2,279	1,157	1.97	2.01	2.53	1.51	2.22	1.57
3	5L., S.B., Fl.....	2,508	1,206	2.08	2.21	2.32	2.04	2.18	1.63 ⁽¹⁾
4	5L., S.B., Fl., S.D.....	2,278	908	2.51	2.56	2.60	2.49	2.83	2.08 ⁽¹⁾

(¹) One plot only.

TABLE 17.—Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet with Alfalfa Irrigated at Different Stages of Growth, 1923 to 1927, with Five-year Averages of Crop Yield, Total Water Used and Yield per Acre-foot of Water

Number of irrigations and stages of plant growth when irrigated	5-year average wheat yield in pounds		Total water used by crop, evaporated and percolated					
	Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
0 Dry.....	3,108	2,988	1.04	1.33	0.85	0.70	1.07	1.24 ⁽¹⁾
1 Fall.....	6,608	4,557	1.45	1.48	1.62	1.29	1.49	1.38
1 E.S.....	6,908	4,486	1.54	1.59	1.32	1.47	1.62	1.70
1 12" H.....	5,984	4,156	1.44	1.65	1.33	1.33	1.48	1.43
1 B.I.C.....	4,908	3,385	1.45	1.50	1.33	1.36	1.40	1.64
1 A.I.C.....	4,964	3,354	1.48	1.61	1.30	1.29	1.57	1.61
2 F., 12" H.....	6,756	3,518	1.92	1.89	2.18	2.26	1.90	1.38
2 F., B.I.C.....	6,336	3,076	2.06	1.88	2.29	2.31	2.07	1.76
2 F., A.I.C.....	6,456	3,165	2.04	1.96	2.16	2.31	1.97	1.78
2 E.S. 12" H.....	6,844	3,680	1.86	2.07	1.87	1.89	2.06	1.43
2 E.S., B.I.C.....	6,548	3,307	1.98	2.12	1.85	1.91	2.04 ⁽¹⁾	1.96
2 E.S., A.I.C.....	6,612	3,391	1.95	1.97	1.69	1.98	1.97	2.12
3 F., 12" H., A.I.C.....	7,268	3,216	2.26	2.27	2.45	2.15	2.66	1.78
3 E.S., 12" H., A.I.C.....	7,396	3,069	2.41	2.51	2.26	2.51	2.51	2.25 ⁽¹⁾
4 E.S., 12" H., A.I.C., 2nd 12" H.....	6,908	2,587	2.67	2.94	2.66	2.64	2.86	2.25
5 F., E.S., 12" H., A.I.C., 2nd 12" H.....	7,468	2,457	3.04	3.23	3.45	2.93	3.33	2.27
Crop needs.....	7,324	5,954	1.23	1.62	0.92 ⁽²⁾	0.58	1.61	1.44

(¹) One plot only.

(²) Dry by mistake.

TABLE 18.—Total Water Used by the Crop, Evaporated from the Soil and Percolated Below Six Feet with Potatoes Irrigated at Different Stages of Growth, 1923 to 1927 inclusive, with Five-year Averages of Crop Yield, Total Water Used and Yield per Acre-foot of Water

Number of irrigations	First irrigation	Subsequent irrigations	5-year average yields of marketable potatoes in pounds		Total water used by crop, evaporated and percolated					
			Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
0	Dry.....		14,055	16,343	0.86	1.20	0.94	0.60	0.88	0.66
1	Fall.....		19,540	19,939	0.98	0.94	1.33	0.96	0.99	0.66
1	Half-grown...		16,956	15,148	1.12	1.24	1.13	0.95	1.26	1.02
1	S.B.....		19,419	16,457	1.18	1.24	1.31	1.20	1.34	0.80
1	F.B.....		19,040	16,702	1.14	1.22	1.19	1.12	1.20	0.98
1	10 d.a.F.B.....		19,435	17,048	1.14	1.22	1.30	1.20	0.98	1.02
2	Fall.....	S.B.....	21,516	17,076	1.26	1.35	1.53	1.06	1.58	0.80
2	Fall.....	F.B.....	21,253	15,181	1.40	1.37	1.49	1.53	1.64	0.98
2	S.B.....	F.B.....	21,014	16,290	1.29	1.29	1.25	1.32	1.48	1.12
2	F.B.....	In 10 days.....	20,943	16,110	1.30	1.23	1.36	1.21	1.38	1.33
3	S.B.....	Every 10 days.....	20,817	13,695	1.52	1.52	1.34	1.29	2.18	1.25
3	S.B.....	Every 20 days.....	22,559	15,558	1.45	1.56	1.46	1.18	1.60	1.45
4	S.B.....	Every 10 days.....	20,409	12,005	1.70	1.85	1.80	1.50	1.84	1.53
4	Half-grown...	F.B. ev. 10 days.....	18,830	11,918	1.58	1.66	1.24	1.48	1.78	1.74
5	S.B.....	Every 10 days.....	23,171	11,883	1.95	1.75	2.00	1.74	2.07	2.17
6	S.B.....	Every 10 days.....	22,254	10,648	2.09	1.68	2.22	1.94	2.13	2.48

TABLE 19.—Relation of Yield of Wheat Following a Cultivated Crop to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

YIELDS OF GRAIN IN POUNDS PER ACRE

Total water used in acre-feet per acre	1,001-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-3,500	3,501-4,000	4,001-4,500	Total	Mean yield
0-0.25									
0.26-0.50									
0.51-0.75	1				1			2	2,250
0.76-1.00		1	1	1	1			4	2,500
1.01-1.25	1	3	3	3		1	1	12	2,458
1.26-1.50		4	7	6	4	1		22	2,545
1.51-1.75		2	6	6	3	1		18	2,611
1.76-2.00		1	2	4	2	1		10	2,750
2.01-2.25			2	3				5	2,550
2.26-2.50			3	1	2			6	2,667
2.51-2.75					2			2	3,250
2.76-3.00				1				1	2,750
Totals	2	11	24	25	15	4	1	82	
Mean water used	0.875	1.352	1.615	1.655	1.708	1.500	1.125		

TABLE 20.—Relation of Yield of Wheat After Wheat to the Total Water Used by the Crop Evaporated from the Soil and Percolated Below Six Feet

YIELD OF GRAIN IN POUNDS PER ACRE

Total water used in acre-feet per acre	0-500	501-1,000	1,001-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-3,500	Totals	Mean yield
-0.25									
0.26-0.50									
0.51-0.75									
0.76-1.00	1			1	1	1		4	1,750
1.01-1.25				2	7	5	1	15	1,417
1.26-1.50			2	4	6	4	1	17	2,191
1.51-1.75			1	3	6	4		14	2,214
1.76-2.00				2	6	1		9	2,194
2.01-2.25				4	1	2	1	8	2,500
2.26-2.50					1	1		2	2,500
2.51-2.75				1	1	1		3	2,250
2.76-3.00					1			1	2,250
Totals	1		3	17	30	19	3	73	
Mean water used	0.875		1.458	1.669	1.580	1.559	1.542		

TABLE 21.—Relation of the Yield of Alfalfa to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

YIELDS OF HAY IN POUNDS PER ACRE

Total water used in acre-feet per acre	0-1,000	1,001-2,000	2,001-3,000	3,001-4,000	4,001-5,000	5,001-6,000	6,001-7,000	7,001-8,000	8,001-9,000	9,001-10,000	Totals	Mean yield
0-0.25												
0.26-0.50												
0.51-0.75	1								1		2	4,500
0.76-1.00				1	1						2	4,000
1.01-1.25	1		1								2	1,500
1.26-1.50				2	3	7	4	2	2		20	5,850
1.51-1.75					2	5	2	1	1	1	12	6,250
1.76-2.00					1	4	4	6	1		16	6,625
2.01-2.25						6	2	2	1	1	12	6,584
2.26-2.50						2	3	1	1		7	6,643
2.51-2.75						1	1	1	2	1	6	6,667
2.76-3.00							1	1		1	3	7,833
3.01-3.25								1			1	7,500
3.26-3.50							1	1			2	7,000
Totals	2		1	3	7	25	18	16	9	4	85	
Mean water used	0.875		1.125	1.212	1.446	1.815	2.030	2.141	1.847	2.312		

TABLE 22.—Relation of the Yield of Marketable Potatoes to the Total Water Used by the Crop Evaporated from the Soil, and Percolated Below Six Feet
YIELD OF MARKETABLE POTATOES IN POUNDS PER ACRE

Total water used in acre-ft. per acre	7,001- 9,000	9,001- 11,000	11,001- 13,000	13,001- 15,000	15,001- 17,000	17,001- 19,000	19,001- 21,000	21,001- 23,000	23,001- 25,000	25,001- 27,000	27,001- 29,000	29,001- 31,000	31,001- 33,000	Totals	Mean yield
0-0.25.....															
0.26-0.50.....								2						3	1,500
0.51-0.75.....	1													11	1,891
0.76-1.00.....			2		2	1	1							22	2,009
1.01-1.25.....		1		1	3	5	3	2	2				1	20	2,090
1.26-1.50.....				2	3	3	1	3	1					13	1,954
1.51-1.75.....				1	3	3	1	2	2					6	1,933
1.76-2.00.....				1	2		2	1				1		5	2,120
2.01-2.25.....				1		1	2							1	2,400
2.26-3.00.....	1		2		15	11	10	10	1			2	1	81	
Totals.....				7					10	9					
Mean water used.....	0.625	1.125	0.875	1.339	1.402	1.307	1.525	1.300	1.400	1.264	1.250	1.750	1.125		

RELATION OF WATER USED TO YIELD OF WHEAT.—The data in tables 15, 16, 19 and 20 show that several good yields of wheat were obtained with a use of 1.00 to 1.25 acre-feet of water, indicating that when water was applied in the proper stages, good yields were obtained with this small amount of water which was the equivalent of about one irrigation plus the precipitation of the plant season. With the wheat after a cultivated crop, the individual plot yields that fell in the higher yield-classes were greater with each increased amount of water used up to 1.75 to 2.00 acre-feet. The wheat after wheat showed as great a percentage of observations in the higher yield-class with 1.00 to 1.25 acre-feet as with the increased amount of water. A larger percentage of observations was in the higher yield-class, however, with 1.50 to 1.75 feet of water than with 1.25 to 1.50 feet.

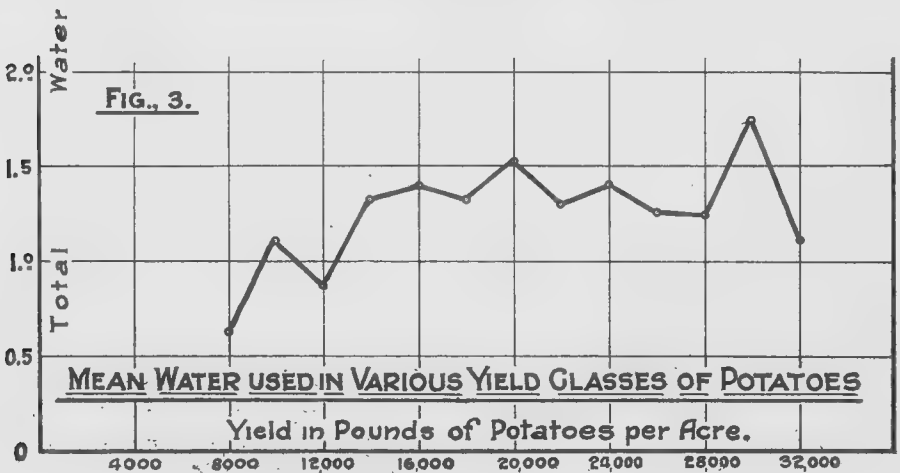
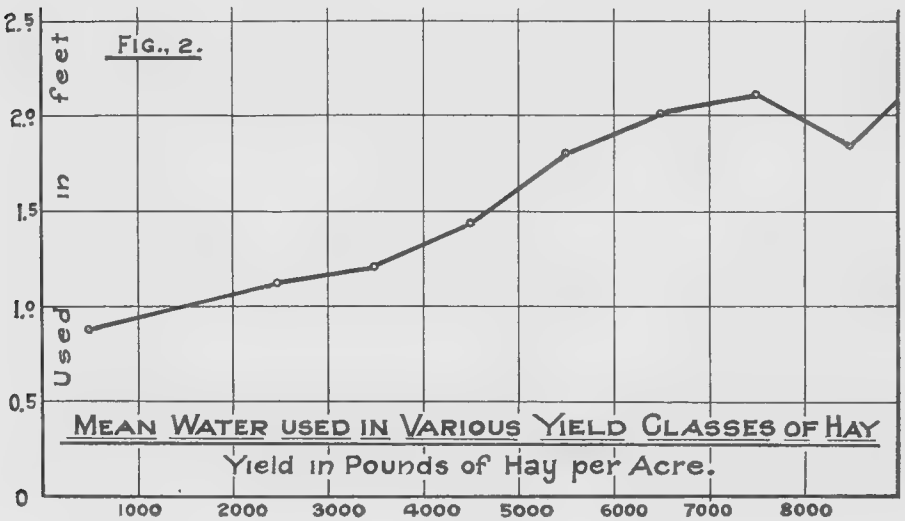
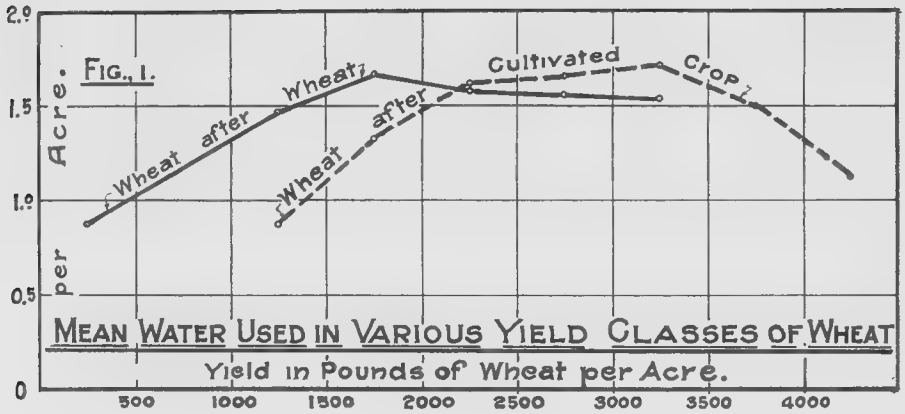
The course of both curves in fig. 1 show a distinct increase in the amount of water used with an increase in the yield to about 1,750 pounds per acre in wheat following wheat and to about 2,250 pounds in wheat following a cultivated crop. Higher yields than these showed but little difference in the total water used to produce the crop except on the wheat after cultivated crop where the extremely high yields appear to have been secured with a comparatively low use of water. There were so few individual observations that fell in these high yield-classes, however, that much importance cannot be attached to the downward curve for the higher yields. In fact there were so few individual observations in both the extremely high and extremely low yield classes of all crops reported that the end portions of the various curves may have little significance.

The wheat-yield curves and the table data show quite clearly that from 1.50 to 1.70 feet of water were required to produce good crops of wheat.

As the amount of precipitation that fell between the time the crops were planted and harvested varied from six inches to fifteen inches, the amount of irrigation water necessary to make up the deficiency of the precipitation would be from 0.50 to 1.00 acre-foot. This would require from one to two 6-inch irrigations applied at the proper stages of plant growth. This was the number of irrigations found necessary in the irrigation tests. If the moisture content of the soil was high from a fall irrigation or heavy fall and spring precipitation, some of this soil water would be available for plant use and on such soils, less irrigation water would be required. If the soil was exceptionally dry in the spring, more irrigation water would have to be used as some would be needed to bring the soil moisture content up to where the plants could readily secure the water they required.

RELATION OF WATER USED TO YIELD OF ALFALFA.—The highest five-year average yield of alfalfa hay was secured with an average of 3.23 acre-feet of water (table 17). The yield was but little less, however, with the use of 2.26 or 2.41 acre-feet. There was little consistent difference in the yields with a water-use of between 1.45 and 2.06 feet, the variations apparently being due to the difference in the time of irrigating. A few high yields are shown in table 21 with a water use of 1.26 to 1.50 feet. The plots recording a water-use of 1.76 to 2.00 feet had the highest percentage of individuals in the yield-class of from 7,001 to 8,000 pounds of hay per acre. This yield-class was the highest of any having enough observations falling in it to make comparisons worth while.

The chart of the mean water used for each yield-class of alfalfa (fig. 2) shows an approximately straight line trend for this crop in contrast to the irregular curves of the other crops. The simultaneous and commensurate increases in water-use and alfalfa yield suggest a fairly high positive correlation of these factors. There is a tendency for the line to flatten out when more than two feet of water are used. The irregular line beyond this point may have been due to the unreliability of the few observations in the higher yield classes.



The data in tables 17 and 21 indicate a water-use of alfalfa of 1.75 to 2.25 acre-feet per acre, or 21 to 27 inches, which is slightly less than was found necessary by Snelson (37) at Brooks, Alberta. With a rainfall of 6 to 15 inches, this would require the addition of one to three irrigations applied at the proper growth periods.

RELATION OF WATER USED TO YIELD OF POTATOES.—The five-year average yields of marketable potatoes increased with an increase of total water used, up to 1.95 acre-feet (table 18). There was a slight decrease in yields with more than 1.95 feet of water. The average yields from 1.45 feet of water were almost as good as from 1.95 feet when the crops were irrigated at intervals of twenty days beginning in the starting-bloom stage.

Of the eleven observations of crops grown with 0.76 to 1.00 foot of water, four (or 36 per cent) gave yields of 21,000 pounds or more (table 22). Of twenty-one observations with 1.01 to 1.25 feet of water, eight (or 38 per cent) had yields above 21,000 pounds. With 1.26 to 1.50 feet of water, eleven of twenty observations (or 56 per cent) had yields above 21,000 pounds, and with 1.50 to 1.75 feet of water, four of twelve observations (or 33 per cent) were in the yield-classes above 21,000 pounds.

The graph representing the mean water used for each yield class of potatoes (fig. 3) is somewhat irregular but shows the general trend of increased water use with increased yield until from 1.30 to 1.50 feet of water were used. From that point higher yields were obtained without any regular increase of water.

The data presented in these tables and the chart indicate a water use of potatoes of about 1.50 acre-feet per acre. A crop season rainfall varying from six inches to fifteen inches would have to be supplemented with from three to twelve inches of irrigation water. This would require from one to three four-inch irrigations given at such times as to be of maximum benefit to the crop. This is in agreement with the number of irrigations found necessary in the irrigation tests.

Depth of Penetration of a Six-Inch Irrigation

One of the important reasons for making soil-moisture determinations before and after irrigation in these experiments, was to note if the amount of water applied (six-acre inches) was sufficient to penetrate below the principal feeding-zone of the plant roots. Numerous observations made by Weaver (40) and others show that wheat roots may have a working depth of 3.5 to 4.0 feet, potatoes 1 to 4 feet, and sugar beets down to 5 or 6 feet. Sunflowers had the majority of their root system in the top three feet of soil. From the information available, it seemed that the water requirements of the plants would be met, if the water penetrated into the soil to a depth of six feet. Observations during the progress of these experiments have confirmed this opinion even for alfalfa which is known to root much deeper than most field crop plants.

It seemed obvious that the depth to which a given application of water would penetrate would be influenced by the degree of wetness of the soil at the time of irrigating. The data in tables 23, 24 and 25 show the relation between the depth to which the water penetrated into the soil and the percentage of moisture in the soil (dry basis) before irrigating for wheat following a cultivated crop, wheat following wheat, and for alfalfa. The potato, sugar beet, and sunflower plots are not included, as the amount of water applied at each irrigation varied from three to four inches, thus making too few observations available with either depth of application to permit of reliable comparisons. Table 26 is a combination of tables 23, 24 and 25.

The depth to which water penetrated was determined by comparing the percentage of moisture in each foot of the top six feet of soil before irrigation and after irrigation. (The method of securing soil samples and of making moisture determinations is stated in the introduction of this paper.) The soil of the different depths secured after irrigation that had appreciably more moisture than the soil from the same depth before irrigation was considered to have received the additional water from the irrigation or the water had penetrated to that depth. In a few instances the samples secured after irrigation showed a lower moisture content in the upper feet of soil than those secured before irrigation. This was shown at times to be due to soil heterogeneity. Some may have been due to mistakes in sampling or in making the moisture determinations. The number of such observations, however, was not large and they were not used in the data reported. The soil samples taken before irrigation were secured either on the day before irrigating or on the day that the water was applied. Samples after irrigation were obtained from three to five days after irrigating.

The percentage of moisture in the soil presented in tables 23, 24 and 26 is the average moisture to the depth to which the water percolated as shown by each individual observation. For example, if the water percolated to a depth of four feet, then the moisture percentage shown is the average for the top four feet of soil before irrigation.

A comparison of tables 23, 24 and 25 reveals but little difference in the depth to which a six-inch irrigation penetrated into the soil supporting a crop of alfalfa and into the soil on which wheat was grown, since there is as close an agreement between the data from the wheat plots and the alfalfa plots as between the data from the two series of wheat plots. As the border surrounding each plot prevented any of the water applied from draining off the plot, the fact that the water soaked into the top foot of the uncultivated alfalfa field more slowly than it did into the looser top soil of the grain field, did not appear to influence the depth to which the water had penetrated by the fourth or fifth day.

From the data presented in each of these tables, it is evident that the water applied soaked more deeply into the moist soil than it did into the drier soil. One interesting feature is that if the water failed to penetrate to the full six feet in the drier soils, it usually went down only three or four feet and *seldom* five feet. This was especially true in the grain plots. The reason for this may have been that the moisture content of the sixth foot of soil supporting a crop was usually higher before irrigating than the moisture content of the third, fourth and fifth feet. The dryness of these depths compared with the sixth foot indicates that the principal working zone of the plant roots was in those foot-depths. If the water percolated into the fifth foot, there appears to have been some movement into the moist sixth foot, thus increasing the moisture content at that depth.

Only six observations are available where the moisture content of the soil before irrigation was seven per cent or less. In none of these plots did the water penetrate six feet, only one was wet down five feet, two were wet four feet and three were wet three feet. Of seventeen observations with a moisture content before irrigation of 7.1 to 8.0 per cent, five (or twenty-nine per cent) showed an increase of water in the sixth foot. Eleven out of forty-eight (or twenty-three per cent) with a moisture content of 8.1 to 9.0 per cent, twenty-two out of fifty-eight (or thirty-eight per cent) with a moisture content of 9.1 to 10.0 per cent and thirty-one out of seventy-three (or sixty-one per cent) with a moisture content of 11.1 to 12.0 per cent, showed that the water applied had penetrated six feet into the soil. The increase in the relative number of

observations that showed the water to have gone down six feet was greater between soils with a moisture content of 10·1 to 11·0 and 11·1 to 12·0 than in any other consecutive class-groups. It appears that with a soil-moisture content of less than eleven per cent, the water moved relatively less freely than it did when there was more than eleven per cent of moisture in the soil. The increases from 12·1 to 13·0 per cent and from 13·1 to 14·0 per cent were also important, but not as significant as the increase between the two preceding class-intervals. It seems that when the moisture content was at about eleven to fourteen per cent it was at what Widtsoe and McLaughlin (46) defined as the point of lento-capillarity or the point above which water may move freely from place to place under surface tension. It is interesting to note that these investigators placed this point at between twelve and thirteen per cent for the Greenville Loam.

When the top six feet of soil contained an average of more than fourteen per cent, almost all the observations showed the water to have penetrated to a depth of at least six feet. It would seem, then, that when this type of soil contains less than fourteen per cent moisture, a six-inch irrigation is not sufficient to insure that the soil will be wet to a depth of six feet, but if the soil moisture is above fourteen per cent, a six-inch irrigation appears to be ample.

TABLE 23.—Relation of the Depth of Penetration of Moisture in the Soil Immediately Before Irrigation, Wheat After Cultivated Crop

Percentage of moisture in the soil																		
Depth of penetration (ft.)	7.1-8.0	8.1-9.0	9.1-10.0	10.1-11.0	11.1-12.0	12.1-13.0	13.1-14.0	14.1-15.0	15.1-16.0	16.1-17.0	17.1-18.0	18.1-19.0	19.1-20.0	20.1-21.0	21.1-22.0	22.1-23.0	23.1-24.0	Totals
-1				1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
2				5	.....	.....	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	15
3				2	.....	.....	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	19
4				4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19
5																		14
6																		13
1																		183
Totals...	1	8	7	17	27	36	27	16	33	30	18	9	11	1	.....	3	1	245

TABLE 24.—Relation of the Depth of Penetration of a Six-Inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation. Wheat.

Percentage of moisture in the soil																		
Depth of penetration (ft.)	7.1-8.0	8.1-9.0	9.1-10.0	10.1-11.0	11.1-12.0	12.1-13.0	13.1-14.0	14.1-15.0	15.1-16.0	16.1-17.0	17.1-18.0	18.1-19.0	19.1-20.0	20.1-21.0	21.1-22.0	22.1-23.0	23.1-24.0	Totals
-1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Totals..	2	3	9	14	14	21	17	20	19	20	21	14	13	5	2	1	3	198

TABLE 25.—Relation of the Depth of Penetration of a Six-Inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation. Alfalfa.

Percentage of moisture in the soil																		
Depth of penetration (ft.)		5.1- 6.0	6.1- 7.0	7.1- 8.0	8.1- 9.0	9.1- 10.0	10.1- 11.0	11.1- 12.0	12.1- 13.0	13.1- 14.0	14.1- 15.0	15.1- 16.0	16.1- 17.0	17.1- 18.0	18.1- 19.0	19.1- 20.0	Totals	
-1		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
2		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
3		2	1	4	11	9	5	2	3	.....	.....	1	1	.....	1	.....	37	
4		1	1	2	11	16	15	6	3	3	1	1	.....	.....	.....	1	61	
5		.....	1	5	6	1	5	5	5	.....	.....	.....	.....	.....	.....	.....	25	
6		.....	.....	3	9	16	17	18	28	19	4	6	1	.....	1	.....	122	
Totals.....		3	3	14	37	42	42	28	36	22	5	8	2	.....	2	1	245	

TABLE 26.—Relation of the Depth of Penetration of a Six-Inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation. Combination of
Tables 23, 24 and 25

Percentage of moist re in the soil																				
Depth of penetration (ft.)	5.1- 6.0	6.1- 7.0	7.1- 8.0	8.1- 9.0	9.1- 10.0	10.1- 11.0	11.1- 12.0	12.1- 13.0	13.1- 14.0	14.1- 15.0	15.1- 16.0	16.1- 17.0	17.1- 18.0	18.1- 19.0	19.1- 20.0	20.1- 21.0	21.1- 22.0	22.1- 23.0	23.1- 24.0	Totals
-1						1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
2						6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	17
3						10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	61
4						14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	61
5						20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	91
6						15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	47
Totals.....	3	3	17	48	58	73	69	93	66	41	60	52	39	25	25	6	2	4	4	688

Water Retained in the Soil from Fall Irrigation

One of the purposes of these experiments was to test the value of a fall irrigation. Since an important factor affecting the value of fall irrigation is the ability of the soil to retain the water until the following crop season, the moisture in the top six feet of soil of all fall-irrigated plots was determined four or five days after the fall irrigation. Similar moisture determinations were again made in the spring so that the difference in the total water in the soil in the fall and spring could be noted. This difference represents the water that was lost from the top six feet of soil less the water added to the soil by precipitation between the time of securing the fall and spring samples.

In tables 27, 28, 29 and 30 is presented the number of feet of water in the six feet of soil in the fall after irrigating and in the spring before irrigating together with the difference between the two. There are two observations shown in most cases for each irrigation treatment. These are for duplicate plots. The data for the fall of 1926 and the spring of 1927 are not given as the heavy fall and spring rains of that period made such data of little value.

TABLE 27.—A Comparison of the Fall and Spring Water Content of the Top Six Feet of Soil of Fall Irrigated Plots Sampled After Irrigating in the Fall and Before Irrigation the Following Spring. Wheat after a Cultivated Crop

Acre-Feet per Acre												
	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	0.96	1.13	0.96	0.86	0	-0.27	1.71	1.67	1.61	1.50	-0.10	-0.17
Fall, Fl.....	1.19	1.01	0.95	1.17	-0.24	+0.16	1.71	1.92	1.55	1.67	-0.16	-0.25
Fall, S.B.....	1.18	1.04	1.17	1.14	-0.01	+0.10	1.60	1.51	1.58	1.57	-0.02	+0.06
Fall, S.B., Fl.....	1.38	0.93	1.16	0.80	-0.22	-0.07	1.60	1.59	1.54	1.56	-0.06	-0.03
Fall, 5L., S.B., Fl.....	0.83	1.00	0.98	0.79	+0.15	-0.21	1.72	1.73	1.33	1.50	-0.39	-0.23

Acre-Feet per Acre

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	1.76	1.94	1.69	1.76	-0.07	1.18	1.18	1.42	1.08	1.20	-0.10	-0.22
Fall, Fl.....	1.94	Samples	1.71	No	-0.23	.....	1.33	1.71	1.06	.....	-0.27	.....
Fall, S.B., Fl...	1.88	not	1.85	duplica-	-0.03	.....	1.43	1.07	1.12	1.05	-0.31	-0.02
Fall, S.B., Fl...	1.87	taken.	1.68	ceated.	-0.19	.....	1.44	1.27	1.28	1.07	-0.16	-0.20
Fall, 5L., S.B., Fl.....	1.65	.....	1.53	.....	-0.12	.....	1.64	1.23	1.17	1.22	-0.47	-0.01

TABLE 28.—A Comparison of the Fall and Spring Water Content of The Top Six Feet of Soil of Fall Irrigated Plots Sampled after Irrigating in the Fall and before Irrigation the Following Spring. Wheat after Wheat

Acre-Feet per Acre

	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	1.75	1.90	1.54	1.74	-0.21	-0.16	1.02	1.43	1.14	1.18	+0.12	-0.25
Fall, Fl.....	1.80	1.88	1.60	1.71	-0.20	-0.17	1.39	1.51	1.32	1.32	-0.07	-0.19
F., S.B.....	1.95	1.63	1.71	1.65	-0.24	+0.02	1.33	1.34	1.47	1.30	+0.14	+0.05
F., S.B., Fl...	1.87	1.87	1.87	1.62	0	-0.25	1.46	1.13	1.41	1.35	-0.05	+0.22
F., 5L., S.B., Fl.	1.72	1.79	1.66	1.51	-0.06	-0.28	1.37	1.75	1.26	1.24	-0.11	-0.51

Acre-Feet per Acre

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	1.71		1.48	1.42	-0.23		1.48	1.41	1.08	1.16	-0.40	-0.25
Fall, Fl.....	1.76	No					1.48	1.59	1.10	1.25	-0.38	-0.34
Fall, S.B.....	1.79	dupli-	1.71	1.35	-0.08		1.69	1.63	1.13	1.16	-0.56	-0.47
Fall, S.B., Fl.....	1.82	cates.	1.36	1.38	-0.46		1.56	1.63	1.19	1.07	-0.37	-0.56
Fall, 5L., S.B., Fl.....	1.52		1.33	1.42	-0.19		1.56		1.18		-0.38	

TABLE 29.—A Comparison of the Fall and Spring Water Content of the Top Six Feet of Soil of Fall Irrigated Plots Sampled After Irrigating in the Fall and Before Irrigation the Following Spring. Alfalfa

Acre-Feet per Acre

	Fall, 1922		Spring, 1923		Differences		Fall, 1923	Spring, 1924	Differences
	(1)	(2)	(1)	(2)	(1)	(2)			
Fall.....	1.21	1.20	1.05	1.07	-0.16	-0.13	1.04	0.88	-0.16
Fall, 12" H.....	1.29	1.11	0.99	1.13	-0.30	+0.02	1.18	1.10	-0.08
Fall, B.I.C.....	1.17	1.10	1.14	1.01	-0.03	-0.09	1.12	1.10	-0.02
Fall, A.I.C.....	1.08	1.09	1.11	1.10	+0.03	+0.01	1.04	1.10	+0.06
Fall, 12" H., A.I.C.....	1.04	0.97	0.99	1.10	-0.05	+0.13	1.05	1.09	+0.04
Fall, E.M., 12" H., A.I.C., 2nd 12" H.....	1.23	1.10	1.09	1.05	-0.14	-0.05	1.15	1.06	-0.09

Acre-Feet per Acre

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	1.06	1.08	1.22	1.25	+0.16	+0.17	1.32	1.25	1.08	1.11	-0.24	-0.14
Fall, 12" H.....	1.27	1.26	1.23	1.30	-0.04	+0.04	1.33	1.30	0.89	1.09	-0.44	-0.21
Fall, B.I.C.....	1.33	1.21	1.30	1.15	-0.03	-0.06	1.26	1.19	1.02	1.07	-0.24	-0.12
Fall, A.I.C.....	1.19	1.29	1.15	1.30	-0.04	+0.01	1.24	1.18		1.18		0
Fall, 12" H., A.I.C.....	1.19	1.03	1.15	1.19	-0.04	+0.16	1.33	1.06	1.22	1.12	-0.11	+0.06
Fall, E.M., 12" H., A.I.C., 2nd 12" H.....	1.28	1.40	1.23	1.24	-0.07	-0.16	1.36	1.10	1.08	1.10	-0.28	-0.28

TABLE 30.—A Comparison of the Fall and Spring Water Content of the Top Six Feet of Soil of Fall Irrigated Plots Sampled After Irrigating in the Fall and Before Irrigation the Following Spring. Potatoes

Acre-Feet per Acre

	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....		1.51	1.76	1.60		+0.09	1.49	1.99	1.82	1.73	+0.33	-0.26
Fall, S.B.....	1.44	1.40	1.54	1.54	+0.10	+0.14	1.53	1.78	1.51	1.70	-0.02	-0.08
Fall, F.B.....	1.45	1.68	1.63	1.62	+0.18	-0.06	1.63	1.50	1.63	1.46	0	-0.04

Acre-Feet per Acre

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall.....	1.54	1.59	1.53	1.36	-0.01	-0.23	1.47	1.37	1.25	1.15	-0.49	-0.22
Fall, S.B.....	1.41	1.54	1.21	1.26	-0.20	-0.28	1.80	1.53	1.20	1.05	-0.60	-0.48
Fall, F.B.....	1.59	1.41	1.36	1.35	-0.23	-0.06	1.56	1.55	1.43	1.18	-0.13	-0.37

A total of sixty-eight observations (or differentials between fall and spring water content) on the two series of wheat plots are reported in tables 27 and 28. The differences of the water contained in the top six feet of soil in the spring from that in the soil the previous fall, as shown by the moisture determinations, varied from a gain of 0.22 feet to a loss of 0.56 acre-feet. Of the sixty-eight observations, seven showed a loss of 0.40 feet or more, six showed a loss of from 0.30 feet to 0.39 feet inclusive, eighteen from 0.20 to 0.29, thirteen from 0.10 to 0.19, and thirteen had a loss under 0.10 feet. Nine wheat plots showed a gain in the spring over the fall sampling and two showed no change.

There were forty-one observations on alfalfa (table 29). Of this number, two plots had a water loss in the spring of 0.30 acre-feet or more. Five had a loss of from 0.20 to 0.29 feet inclusive, eight from 0.10 to 0.19, and thirteen had a loss of less than 0.10 feet. Twelve observations showed more water in the spring than in the fall, the greatest gain being 0.17 acre-feet per acre. One observation was the same in the spring as in the preceding fall.

Twenty-three observations on potato plots are recorded in table 30. Of these, four showed over 0.30 acre-feet less water in the spring than in the previous fall, six showed a loss of from 0.20 to 0.29 feet inclusive, one a loss of 0.13 feet, six a loss of less than 0.10 feet and five had more water in the spring than in the previous fall. One observation showed no change.

The greatest loss of water appears to have been from the wheat after wheat, the next greatest from the potatoes, the next from wheat after cultivated crop and the least from alfalfa. The greater loss of water from the wheat plots following wheat than from the wheat following a cultivated crop may have been partly due to the fact that the wheat after wheat plots were left in stubble through the winter each year but one and then spring-ploughed while the wheat plots after cultivated crop were cultivated in the fall after harvesting the potatoes or other cultivated crop and were not ploughed in the spring before seeding. The potato plots went through the fall and winter as wheat stubble the same as wheat after wheat, which fact may account for the relatively high water loss from those plots. The alfalfa plots which showed the lowest water loss had the advantage that they were sampled from two to four weeks earlier in the spring than were the wheat plots.

A comparison of the water loss in the different years shows no consistent difference except for the period between the fall of 1925 and the spring of 1926. The loss in this period was higher than for any of the other three periods in each series of plots especially in the wheat after wheat and the potato plots. The only apparent reason for the greater loss in the 1925-1926 period was that between the time of securing the samples in the fall of 1925 and in the spring of 1926, there was very little precipitation (a total of but 2.51 inches). In addition the winter was unusually open and warm, with only nine days that the thermometer went below zero. High winds were also experienced. It seems quite evident that the dry fall and spring and the windy open winter resulted in greater evaporation from the soil than is usual.

GENERAL SUMMARY

1. In this paper are reported the results of experiments with the irrigation of wheat, alfalfa, potatoes, sugar beets, and sunflowers, conducted at the Dominion Experimental Station, Lethbridge. The experiments cover a period of from two to six years.
2. One irrigation produced a good crop of wheat in the years of average rainfall. In the drier seasons, two applications of water were needed.
3. Irrigating in the fall after harvest for the succeeding year's wheat crop proved to be a good practice. If a fall irrigation was not given, and if the precipitation of May and early June was not abnormally high, it was found essential to irrigate after the crop was up in the spring, but before the plants were checked in growth by lack of moisture.
4. Contrary to the usual opinion, irrigating wheat as early as the three-leaf stage did not reduce yields on the sandy clay-loam soils where the experiments were conducted.
5. When wheat needed more than one irrigation, good results were obtained when the second application was made in the flowering stage.
6. Irrigating wheat in the soft-dough stage did not increase yields, but sometimes caused the grain to lodge.
7. In each year of the experiments, except the "wet" year of 1927, alfalfa required at least two irrigations to produce two good crops. It was found necessary to apply one of these the previous fall or in early May to give a heavy first cutting of hay. A second irrigation was required just before or just after cutting the first crop. If May was dry, an irrigation when the first crop was about twelve inches high increased the yields.
8. It seemed to make little difference in the yields of the second crop whether the water was applied ten days before or immediately after cutting the first crop.
9. Irish Cobbler potatoes, irrigated when the plants were half-grown, gave lower yields than were secured if the first irrigation was postponed until the plants were starting to bloom. In the drier seasons an irrigation in the starting-bloom stage and two subsequent irrigations at intervals of twenty days was the most satisfactory practice.
10. There was no consistent difference observable in the cooking quality of potatoes receiving different irrigation treatments. When the plants were retarded in growth from lack of water and then irrigated, second growths, resulting in "knotty" tubers, were prevalent. The potatoes receiving five or six irrigations produced tubers with enlarged lenticels, but the cooking quality did not appear to be impaired. The greater number of irrigations produced more small potatoes than one or two irrigations.
11. The limited data secured with sugar beets suggest that an irrigation in the previous fall and one during the growing season, from six to eight weeks after thinning would be sufficient for that crop in years of average rainfall.
12. There was no uniform difference in the sugar content of the beets receiving different irrigation treatments, except that where the beets were retarded in their growth from drouth and then irrigated, the sugar content was lower than where the beets were not injured by lack of water at any stage of growth.

13. Sunflowers gave best yields on fall-irrigated land or with a spring irrigation when the plants were about six inches high. In the two years of the test with sunflowers, one irrigation in the season was sufficient. This crop wilted noticeably if the soil became too dry, but revived and produced fair yields when water was applied.
14. These experiments indicate that, including the available water in the soil at the beginning of the season, wheat requires from 1.50 to 1.75 acre-feet of water, alfalfa 1.75 to 2.25 acre-feet and potatoes about 1.50 acre-feet to produce good crops.
15. Soil moisture determinations made of each foot-depth of soil to a depth of six feet before and after each irrigation showed that a six-inch application of water failed to penetrate into the soil to a depth of six feet in more than half the plots when the soil moisture content was below eleven per cent at the time of irrigation. With a moisture content between eleven and thirteen per cent, sixty to seventy per cent of the observations showed that the water had penetrated to six feet. The water applied to almost all of the plots having a soil moisture content above thirteen per cent wet down six feet or more.
16. The loss of water from the soil of fall-irrigated land between the time of irrigating in the fall and seeding the following spring was noticeable but usually not important, except in 1925-1926, when the weather between mid-October and early May was very open, dry and windy. During that period, the water-loss from a number of plots was about equal to the irrigation application of the previous fall.

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